Engineering Materials and Design

★ *The Magazine for Engineering Designers*

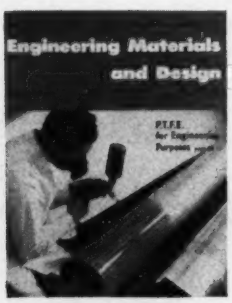
A HEYWOOD PUBLICATION

Vol. 1 No. 2 November 1958

EDITOR
H. R. Heap, B.Sc., A.M.I.E.E.

TECHNICAL EDITOR
R. D. Cullum, A.R.Ae.S.

ASSISTANT EDITORS
F. R. Terrell
P. Burton



COVER—Applying p.t.f.e. dispersion coating at Siemens-Edison Swan Ltd. works (carried out in a spray booth with fume extraction).

Published monthly by HEYWOOD & COMPANY LTD., Drury House, Russell Street, London, W.C.2 (Tel.: TEMple Bar 3422), on the 15th of the preceding month. Annual subscription 35s. sterling per annum ($5.25, U.S.A. and Canada) throughout the world. Single copies to order from all newsagents and bookstalls, 2s. 6d. each (by post from the publishers, 3s. 0d. each). BRANCH OFFICES: Royal Buildings, 2 Mosley Street, Manchester, 2, Tel.: Central 9935; Bayliss House, Hurst Street, Birmingham, Tel.: Midland 5786; 52 St. Enoch Square Glasgow, Tel.: City 3492; 527 Madison Avenue, New York 22, N.Y., Tel.: Plaza 9-1171.

© Heywood & Company Ltd., 1958. Must not be reproduced without written permission.

ISSUE AT A GLANCE

page

P.T.F.E. FOR SPECIAL ENGINEERING PURPOSES **66**
Account of its applications in modern engineering.
By **D. A. Smith**, M.Sc., A.R.I.C., A.I.R.I., A.N.C.R.T.

HOW DESIGN CAN AFFECT THE FATIGUE OF WELDED STRUCTURES ... **72**
How good design can help prevent fatigue failure.
By **T. R. Gurney**, M.A., A.M.I.C.E.

SELECTION OF FRACTIONAL HORSEPOWER ELECTRIC MOTORS **79**
Choosing the right motor for domestic and industrial uses.
By **H. J. Cadoux**, M.A. (Oxon), A.M.I.E.E.

ALUMINIUM STRIP AND FOIL FOR COIL WINDINGS **84**
Examination of their developing applications.
By **D. Worth**, B.Sc. (Eng.), A.M.I.E.E.

EPOXY CASTING RESINS IN ENGINEERING **88**
Unique casting properties provide new uses.
By **P. A. Dunn** and **J. M. Turner.**

STAINLESS STEEL AS A STRUCTURAL MATERIAL **92**
An evaluation of its properties for widening applications.
By **I. L. G. Baillie**, B.Sc., A.M.I.Mech.E.

DESIGN FACTORS IN SILVER BRAZING... ... ... **96**
How the best features of the process can be achieved.
By **L. D. Connell**, A.I.M., A.M.Inst.W.

OTHER FEATURES

Glass Fibre for Rockets and Launchers **71**

New Ideas in Design **76**

Designer's Notebook **100**

Pressures Between Elastic Bodies: Data Sheet **103**

Aluminium Alloys: Data Sheet **105**

REGULAR FEATURES

Materials in the News **59**

Editorial **65**

American Letter **99**

News of Industry **115**

What's New in Materials and Components **107**

This is an Edgar Allen ring casting weighing 4 tons 9 cwt. 2 qrs.

Write for 'Steel Foundry Book' using the request form

To EDGAR ALLEN & CO. LTD. SHEFFIELD, 9
Please post 'Steel Foundry Book' to

Name .....

Firm .....

Address .....

.....

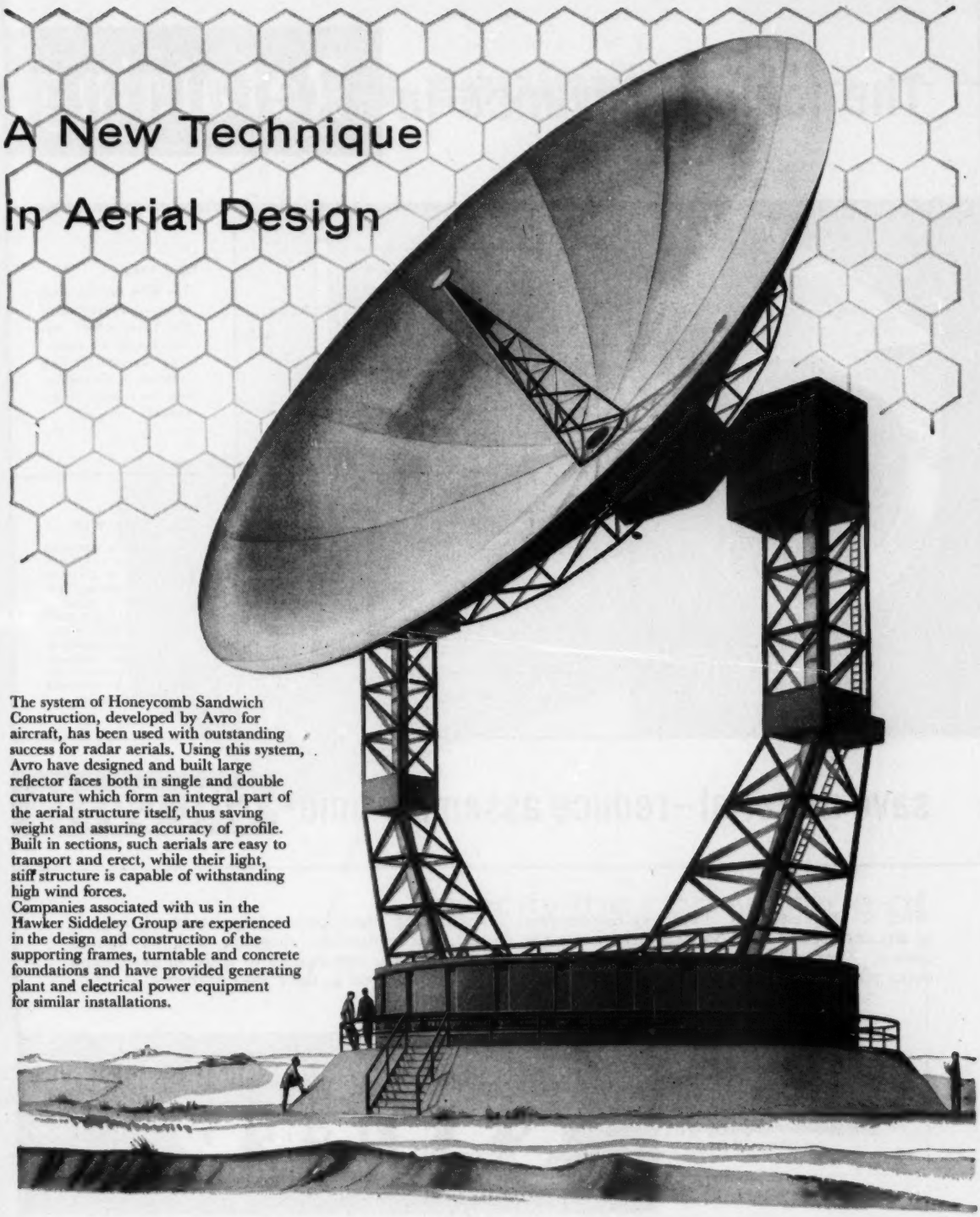
No. 1 E.M.D

EDGAR ALLEN & CO. LIMITED
IMPERIAL STEEL WORKS · SHEFFIELD 9

TELEPHONE: SHEFFIELD 41054 TELEGRAMS: ALLEN, SHEFFIELD, 9

EMD 111 for further information

A New Technique in Aerial Design

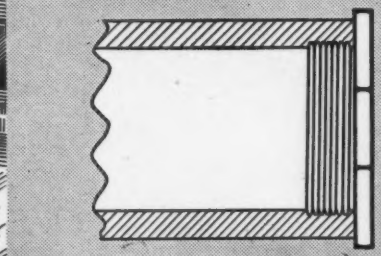


The system of Honeycomb Sandwich Construction, developed by Avro for aircraft, has been used with outstanding success for radar aerials. Using this system, Avro have designed and built large reflector faces both in single and double curvature which form an integral part of the aerial structure itself, thus saving weight and assuring accuracy of profile. Built in sections, such aerials are easy to transport and erect, while their light, stiff structure is capable of withstanding high wind forces.
Companies associated with us in the Hawker Siddeley Group are experienced in the design and construction of the supporting frames, turntable and concrete foundations and have provided generating plant and electrical power equipment for similar installations.

A. V. ROE & CO. LIMITED, Greengate, Middleton, Manchester

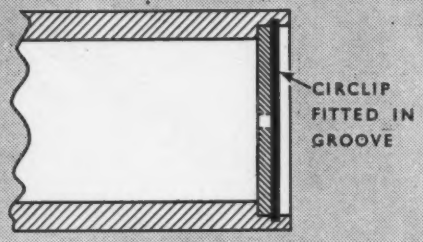
MEMBER OF HAWKER SIDDELEY/ONE OF THE WORLD'S INDUSTRIAL LEADERS

The logical advance in Retaining



OLD WAY

This fluid seal involved internal threading of the tube, which was sealed with an expensive cap-nut. The assembly was laborious and spanners were needed.



THE SALTER WAY

The tube is recessed and then simply grooved with the SALTER Grooving Tool. A Circlip is snapped into position and secures the fluid retaining plate with positive, vibration-free locking. When necessary the Circlip can be removed quickly and easily.

save material–reduce assembly time–cut costs

When it's a question of assembling components in any engineering field, Salter Retainers are the answer. They replace nuts and bolts, screws, cotter pins, and eliminate expensive threading and machining operations. A large standard range is at your immediate disposal, and we should welcome the opportunity to assist in developing special retainers to solve your problems.

Send for the Salter Retainer catalogue—no designer is complete without it.

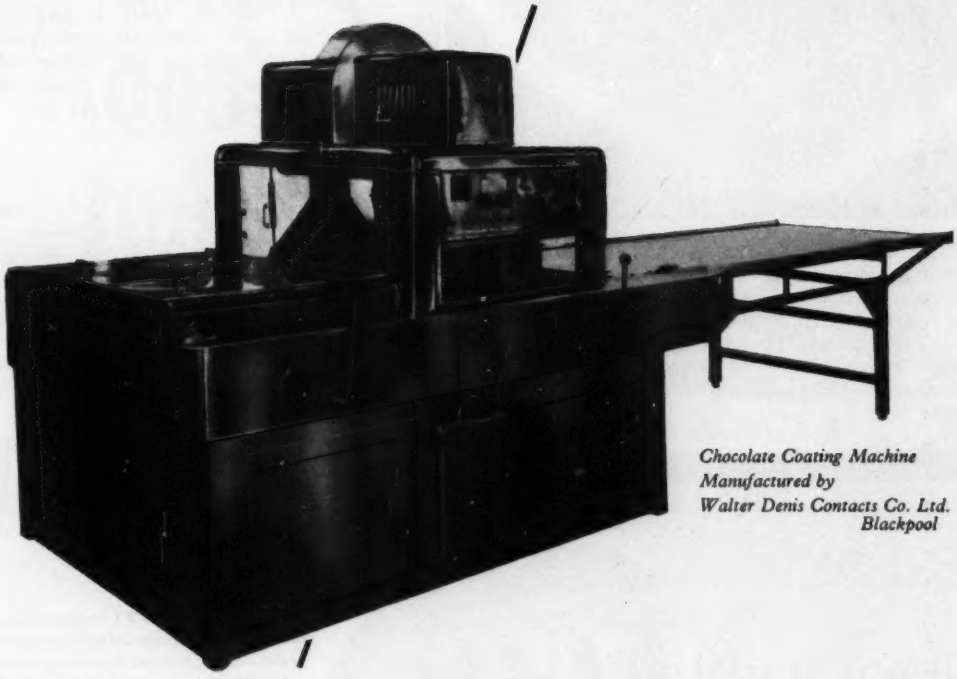
NEATER – MORE POSITIVE – PERMANENT RETAINING

SALTER "TRUARC"

Circlips *Fasteners* *Retainers* *Fixes*

Geo. Salter & Co. Ltd., West Bromwich · Spring Specialists since 1760

designing new equipment?



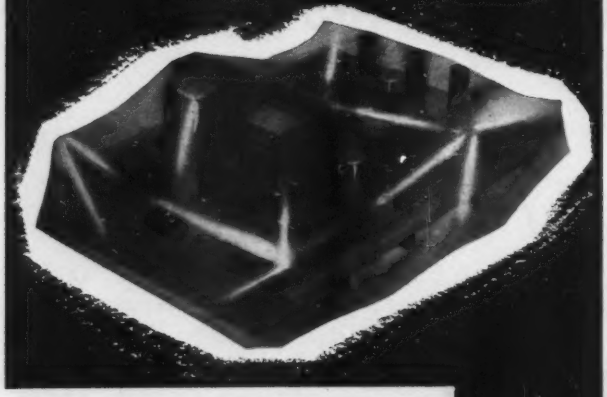
Chocolate Coating Machine
Manufactured by
Walter Denis Contacts Co. Ltd.
Blackpool

specify the correct type of

"Staybrite"
STAINLESS STEEL

FIRTH-VICKERS STAINLESS STEELS LTD · SHEFFIELD
Telephone: Sheffield 42051

The essence of PROTECTION



The exclusion of damp, dust and dirt from delicate and costly machines is one of the biggest headaches of modern times. Natural, Flexible Vinyl covers are light (.010" thick), strong and with all-welded seams, made to measure Send dimensions for quotations without obligation

MANHATTAN

Vitreous enamelled Nameplates & Badges

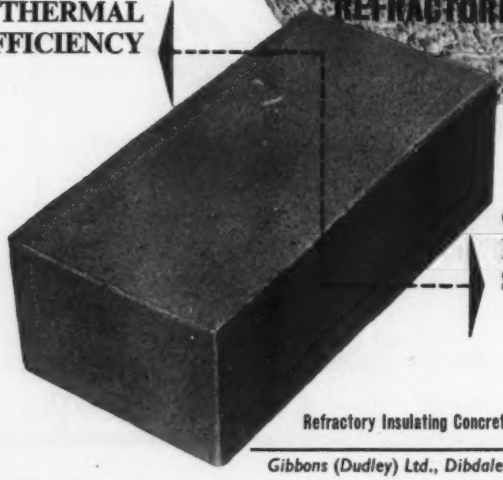
Richmond

May we assist in the design of your nameplates to your specification and colour schemes? Chromium finish or Gold Plated. No charge for designs on firm enquiries

VICKERS JACK OLDING & CO. LTD TRACTORS

139 GREAT CHARLES STREET, BIRMINGHAM 3
Telephone: CENTRAL 2938

GIBBONS "H·T 1" INSULATING REFRACTORIES



In producing the "H.T 1" brick efforts have been concentrated on obtaining a balance between the inter-related properties of thermal efficiency and mechanical strength. Research and development work has resulted in the evolution of entirely new manufacturing methods whereby high insulating value and low heat storage capacity have been attained with an exceptionally high mechanical strength.

Furnace Builders will appreciate the strong even texture of these new "H.T 1" bricks which can easily be cut, sawn or drilled on the job and repeatedly handled without costly waste resulting from crumbling corners and breakage.

Gibbons "H.T 1" insulating refractories have been the leading choice of furnace builders and users for many years and represent today an unrivalled combination of physical properties and economy in price.

QUALITIES NOW IN PRODUCTION FOR SERVICE TEMPERATURES OF 1300°C — 1500°C

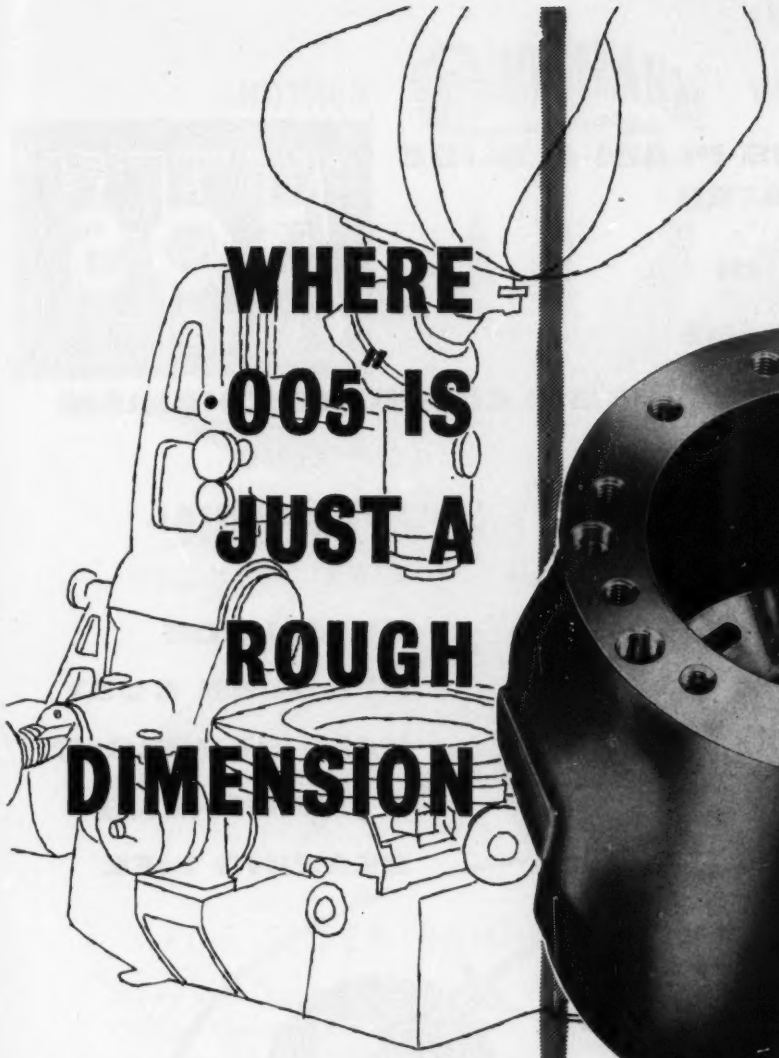
Refractory Insulating Concrete · Concrete Aggregates · Super-Plastic Jointing Cements · Surface Coating Cements

Gibbons (Dudley) Ltd., Dibdale Works, Dudley, Worcs. Telephone: 3141

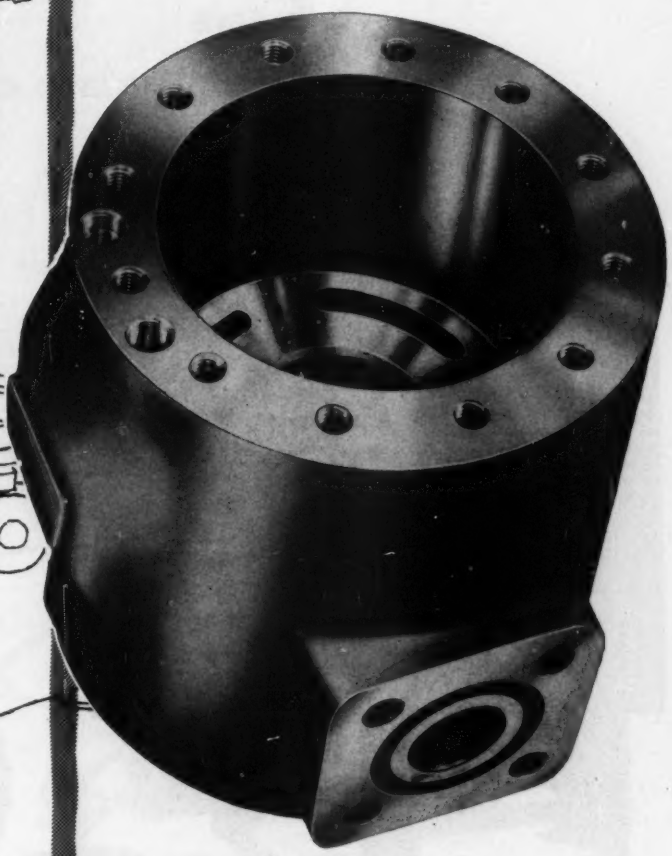
H-W.137

EMD 116 for further information

WHERE ·005" IS JUST A ROUGH DIMENSION



Illustrated here is a hydraulic valve body for Stein-Atkinson Vickers Hydraulics Ltd., made by Harpers and machined by them to limits of ±·002"



For more than a century and a half Harpers have been making fine castings—and machining them to fine limits.

Harpers can supply castings gauged, machined, inspected and tested ready for final assembly. They also have facilities for vitreous enamelling, both on iron and on steel, and for painting and plating as well as for pressed work.

* *Details of the Harper Castings Service will gladly be supplied on request.*

JOHN HARPER & CO LTD

Castings

MACHINED TO FINER LIMITS

JOHN HARPER & CO. LTD.
ALBION WORKS, WILLENHALL

ALZEN BEARINGS PLAIN & SLIDE ARE INCORPORATED

ALZEN 305

IN

THE

FLOOR SELECTING MECHANISM

OF THIS

INDUSTRIAL

LIFT *Photograph by courtesy Aldous & Campbell Ltd.*

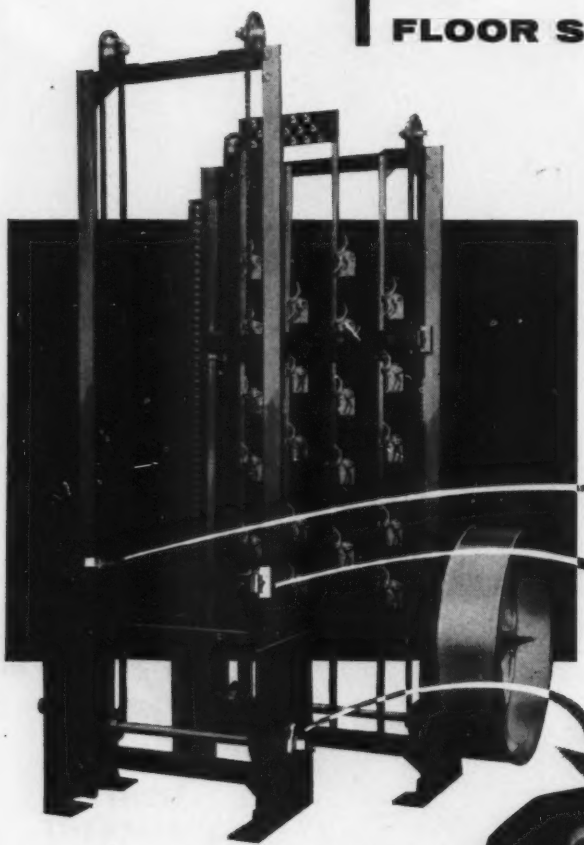
ALZEN 305

REDUCES COST

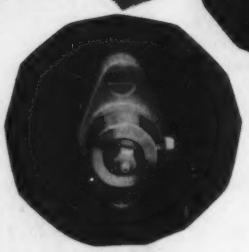
HALVES WEIGHT

& LENGTHENS

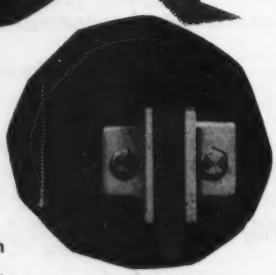
BEARING LIFE



Slide bearing front view



Plain bearing



Slide bearing side view

Alzen 305 White Bronze Bearing Alloy Patent No. 725818 is specified and fitted by Aldous & Campbell Ltd., for its great wear resisting qualities and for its great saving in cost and weight.

Alzen 305 is eminently suitable for most Heavy Duty Bearing Applications and is available in ingot, sand castings, gravity die castings, pressure die castings, chill cast bars cored and solid, and as fully machined components from Hill Alzen (Sales) Ltd., P.O. Box 22 Stringes Lane, Willenhall, Staffs. Telephone Willenhall 227 (5 lines) Telegrams Hill Alzen 227 Willenhall. May we send technical literature and samples for testing?

WhiteAd 394

ANOTHER CRUICKSHANK'S WINNER

FOR SUPER BRIGHT CADMIUM PLATING

A fully bright high-speed Cadmium Plating solution, containing one brightener only. Barrel and vat plating solutions are available and suitable Cadmium solutions can be converted.
A deposit of .0003" is obtained in 8 minutes at 30 amps. sq. ft. The solution has a wide operating range, and REQUIRES NO BRIGHT DIPS.

ANOTHER PRODUCT OF CRUICKSHANK LABORATORIES BACKED BY SERVICE AND EXPERIENCE.

KEY TO QUALITY CADMIUM PLATING

GENEROUS WORKING RANGE

LOW OPERATING COST

EASILY CONTROLLED

APPLICABLE TO VAT OR BARREL

MAXIMUM BRIGHTNESS

CRUICKSHANK'S

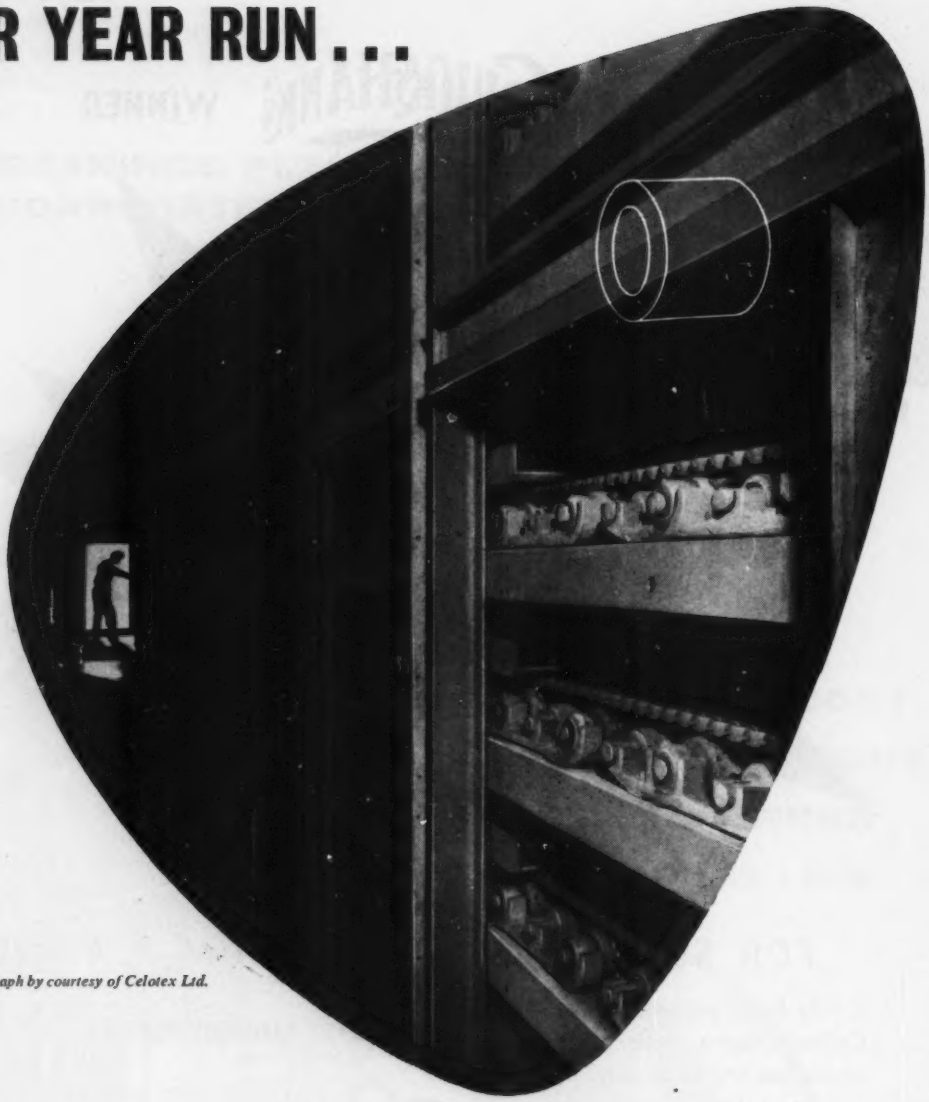
R. CRUICKSHANK LIMITED
CAMDEN STREET - BIRMINGHAM 1
Telephone : CENtral 8553 Telegrams : CRUICKSHANK, BIRMINGHAM

"The sign of good plating"

SM/C 2929

EMD 119 for further information

A FOUR YEAR RUN...



Photograph by courtesy of Celotex Ltd.

This drying conveyor illustrates one of the many applications of MORGANITE CARBON BEARINGS where carbon is the most suitable material. Thousands of tons of Wallboard pass over these rollers every year—4,000 MORGANITE CARBON BEARINGS undergo severe duty to make this possible—each carries a load of about 30 pounds and is subjected to temperatures up to 650°F in a very dry and dusty atmosphere. In spite of these arduous conditions replacement is only necessary after 4 years.

MORGANITE CARBON BEARINGS solved the problem for CELOTEX—perhaps they will solve yours today. Please write or 'phone for leaflet SD.63, or ask for one of our Technical Advisers to call.

MORGANITE CARBON BEARINGS withstand high temperatures; will run in liquids; resist chemical atmospheres and corrosive conditions; need no lubrication; are useful for inaccessible positions; are non-contaminating and eliminate maintenance.

MORGANITE BEARINGS

THE MORGAN CRUCIBLE COMPANY LIMITED, BATTERSEA CHURCH ROAD, LONDON, S.W.11. Telephone: BATtersea 8822

C64a

Nylon

one of nylon's toughest jobs

Nowhere are nylon's virtues more vital than in conveyor belts—especially in those in daily use at the coal face. High tensile strength, abrasion resistance and shock absorption make nylon supreme. It keeps going month after month, for its losses from fatigue, ageing or wet are small. These are the properties that explain the choice of nylon for belts, tyres, vehicle air springs and other tough uses.

BRITISH NYLON SPINNERS LIMITED (B Nylon S) PONTYPOOL · MON

expanding your resources

Genitrons blow new materials for industry

A complete range of blowing agents—The Genitrons—open the door of opportunity to engineers and designers everywhere. They offer new materials—expanded materials—which can perform a virtually unlimited number of tasks more effectively than ever before.

Versatile Genitrons. They can be used for expanding almost any type of plastic or rubber, adding strength to lightness and economising on expensive raw materials.

Whatever your project, it is probable that at some stage Genitron expanded products can be employed—to considerable advantage. Already they are used as insulators against heat and sound, as refrigerator parts; in the shoe industry and in aircraft construction, in upholstery, packaging, and elsewhere in many more industries. Extra hard or soft as sponge: adaptable to any special requirements: plastics or rubber expanded with Genitrons excel in every application . . .vastly increase the scope of engineering design. For full information about Genitron Blowing Agents and some of the materials which have been expanded using them, write for Publication No. M/G6.

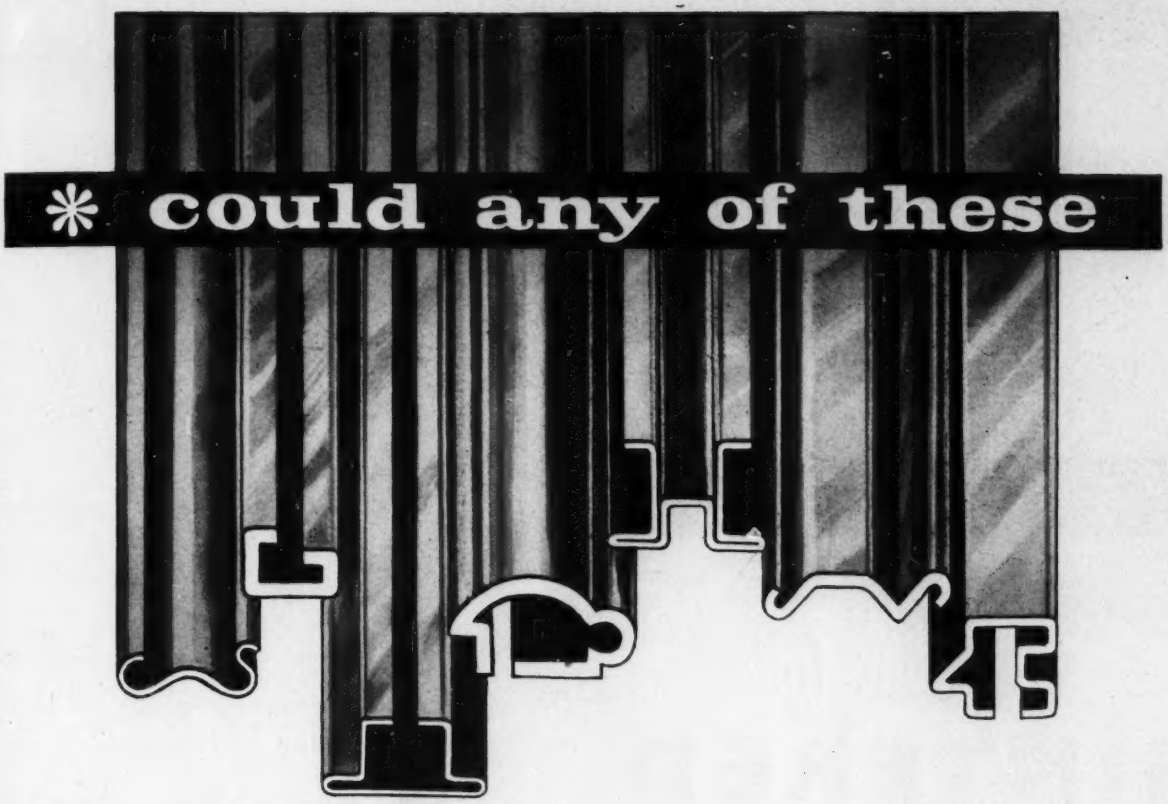
WHIFFENS

A member of the Fisons Group of Companies

chemicals for industry

Whiffen & Sons Ltd., Fison House, 95 Wigmore Street, London, W.1
Telephone: WELbeck 5500 Telegrams: Whiffen, Wesdo, London

W35



* could any of these have a place in your product?

Aircraft sections	Jib built assemblies
Angles	Laths
Angle beads	Louvres
Belt mouldings	Ornamental trim
Building system components	Prefabricated components
Cable covers	Refrigerator frames
Ceiling joists	Roof trusses
Door frames	Skirting "boards"
Drum rings	Suspension strips
Floor joists	Textile machinery parts
Fluorescent lighting reflectors	Venetian blind strip
Greenhouse frames	Welding assemblies

We produce metal sections by a variety of methods, each offering particular advantages in accuracy, quality, delivery and price.

Metsec sections are used to make Buildings, Joists, Trusses, Buses and a million other things you use every day.

Ask us about your problem.

Metal Sections Ltd

OLDBURY · BIRMINGHAM

Telephone: BROadwell 1541

Specify a holiday on the Riviera!

Why buy new machine tools to make small components when SMC Sinterings can supply them in quantity at up to 40% less cost? You save the capital outlay required for new machine tools and you save on production costs—enough to pay for several holidays on the Riviera or anywhere you fancy.

Specify SINTERED METAL COMPONENTS

and save money

Sintered Metal Components are delivered complete and ready to go to work without extra machining **and cost up to 40% less than conventionally cast and machined parts.** SMC will make them for you in quantity (normal minimum 10,000; no maximum; 1,000,000 is routine), with any of an infinite range of finishes and characteristics and with a wear-resistance up to six times that of hardened steel. Dimensions must not exceed 2½″ × 2½″ but shapes may be as complex as you like. **For further details, visit us in Chard and see for yourself or write for full information:**

SMC SINTERED METAL COMPONENTS (CHARD) Ltd

BODEN WORKS . CHARD . SOMERSET

Chard 2341/2. *A member of the Sterling Industries Group.*

JW. Ad 4403

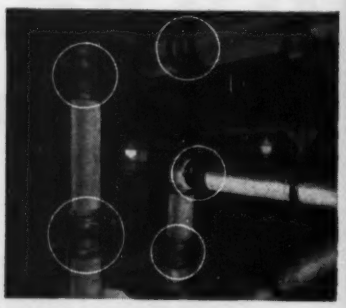
When PIPES MOVE

in nuclear, chemical and gas plants and in marine engineering, where pipes are subject to extreme heat, movement must be effectively and efficiently absorbed. The ideal medium in the past few years has been found in the Stainless Steel Bellows Type Expansion Joint.

TEDDINGTON BELLOWS GIVE THESE ADVANTAGES

- **Highest quality stainless steel.**
- **Butt welding of tube to ensure perfect uniformity of wall for true action.**
- **Maximum durability.**
- **Teddington convolution design ensures flexibility with strength.**
- **Normal production range, 1 inch to 7 feet diameter, and rectangular units up to 24 feet square — when larger bellows are required, we can make them.**

Teddington Bellows are produced in technical collaboration with the Solar Aircraft Co. U.S.A.



Let our engineers advise on your expansion problems.

Send for our brochure No X116

The Modern answer is

TEDDINGTON BELLOWS

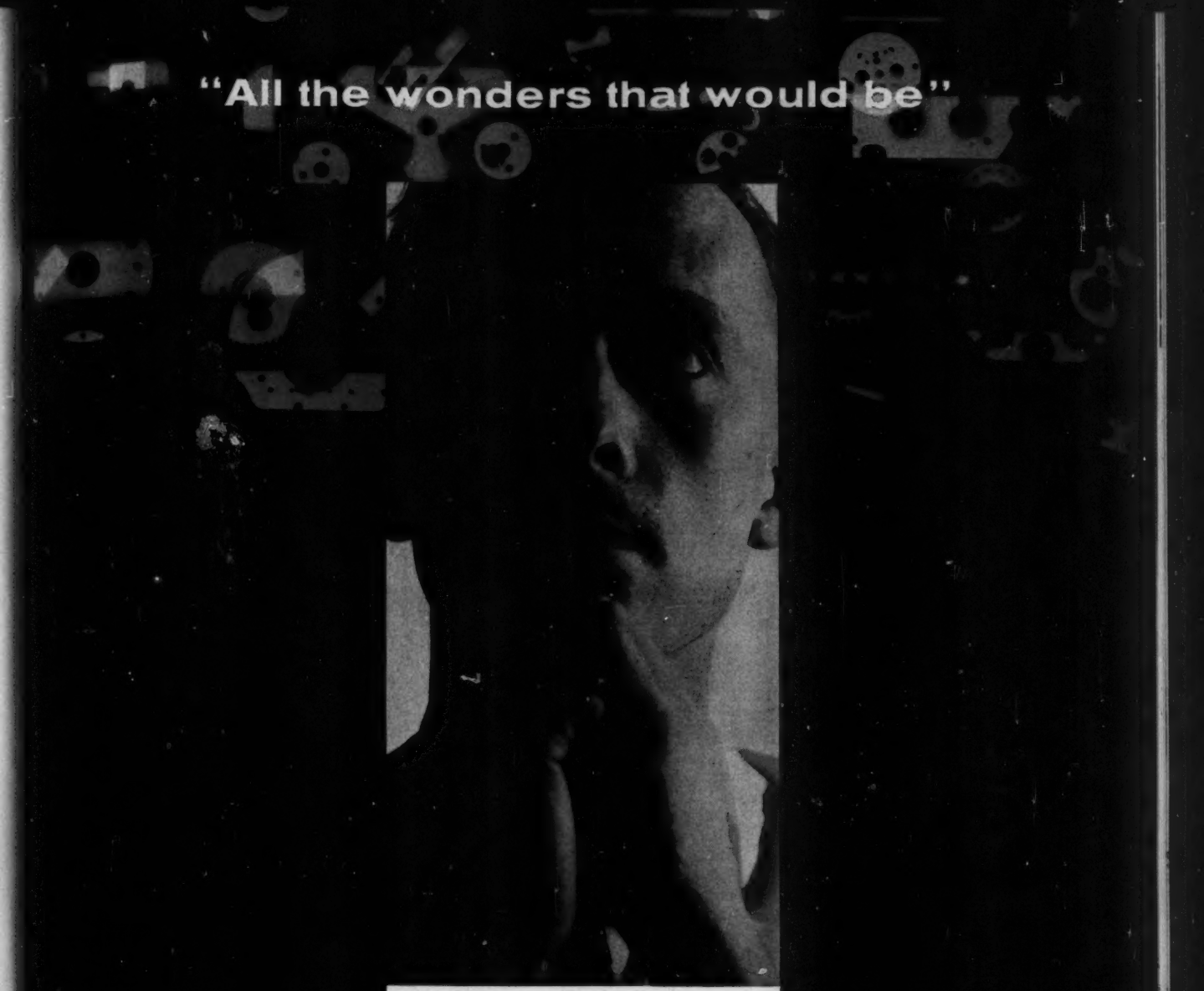
EXPANSION JOINTS

TEDDINGTON AIRCRAFT CONTROLS LIMITED

INDUSTRIAL BELLOWS DIVISION

Ammanford, Carmarthenshire. Ammanford 455.

"All the wonders that would be"



Insulator Division

Electro-ceramic insulators, mass-produced to close dimensional tolerances, for radio, telecommunication and electronic apparatus, cooking, heating and pyrometric equipment.

Electric Heating Division

'Chromalox' ceramic-embedded strip, ring, pad and cartridge electric heating elements and 'Tubalox' sheathed wire elements for domestic and industrial purposes. Also complete appliances including air and immersion heaters.

Gas Burner Division

Non-corrosive ceramic tipped gas jets and gas burners for domestic and industrial heating and lighting together with a comprehensive range of spray jets for chemicals, oils and other fluids.

In the forward march of industry, progress starts with visionaries' dreams... with dreams awaiting translation into practical possibilities. And that's where Geo. Bray have a part to play. In close on a century, the Company has made many dreams come true, turning the ideas of others and of themselves —for Geo. Bray engineers are visionaries too—into solid realities.

For lighting and heating, for electrical insulation, for precision engineering, there is hardly an industry that does not rely on the products of this 95-year-old Company. Today, forward-looking people are constantly coming to the Insulator, Electric Heating and Gas Burner Divisions of Geo. Bray for advice on the development of new ideas in these all-embracing fields.

GEO. BRAY

and company limited

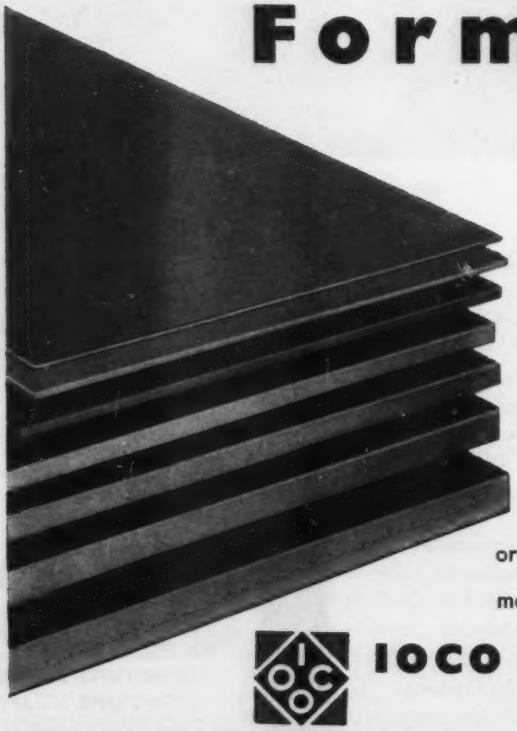
GAS JETS AND BURNERS
ELECTRIC HEATING ELEMENTS
ELECTRO-CERAMIC INSULATORS

Leicester Place, Leeds, 2
Leeds 20981 (9 lines)

London Office:
305 Grand Buildings,
Trafalgar Square, W.C.2

EMD 126 for further information

EMD 127 for further information



Formapex

LAMINATED PLASTIC

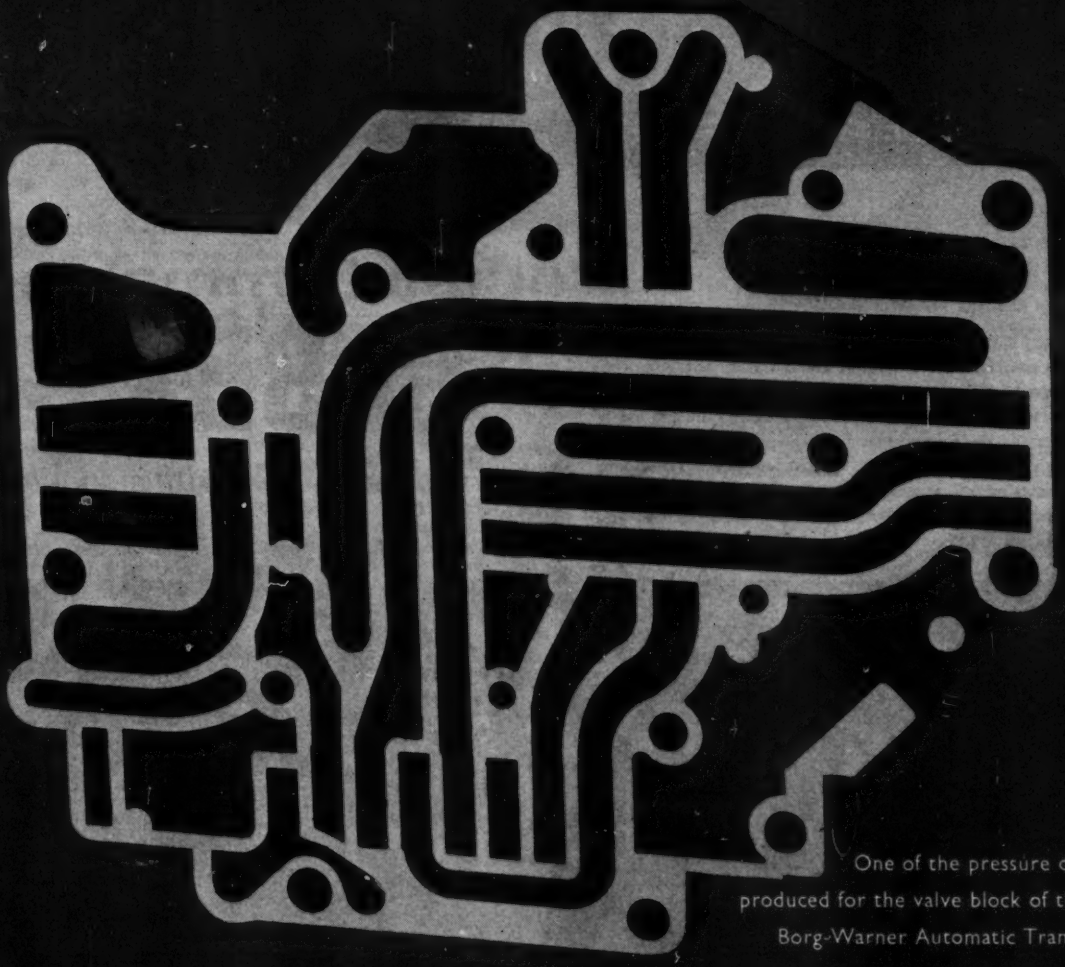
for

GEARS
BUSHES
WASHERS
COLLARS
BEARINGS
SMALL PARTS
JIGS

Fabric and paper base grades in machining and cold or hot punching qualities. High mechanical strength; low co-efficient of friction; resistant to heat, moisture, chemicals. Please write for Brochure 11K.

IOCO LIMITED
ANNIESLAND, GLASGOW W3
Telephone: Scotstoun 5501-6

For all pressure die castings



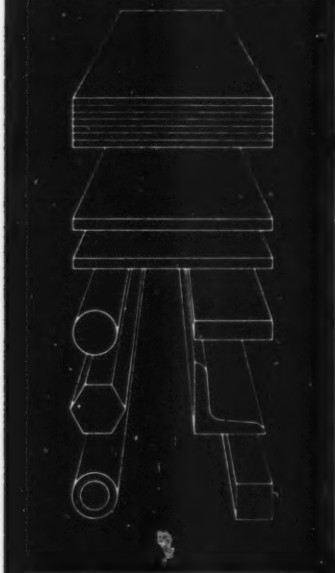
One of the pressure die castings
produced for the valve block of the
Borg-Warner Automatic Transmission

experience has shown

Hiduminium

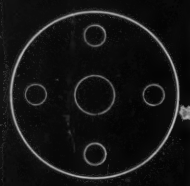
makes the most

HIGH
DUTY
ALLOYS



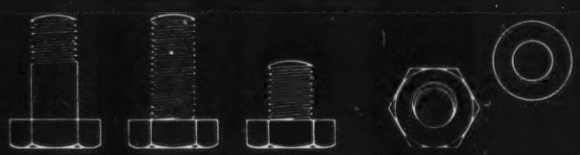
Prompt delivery from stock.

May we help you with your Stainless Steel requirements? A wide range of sizes in the vital specifications required by Nuclear and General Engineers is at your disposal.



Stainless Steels

SHEETS
PLATES
BARS
TUBES
BOLTS
NUTS
FLANGES
FITTINGS



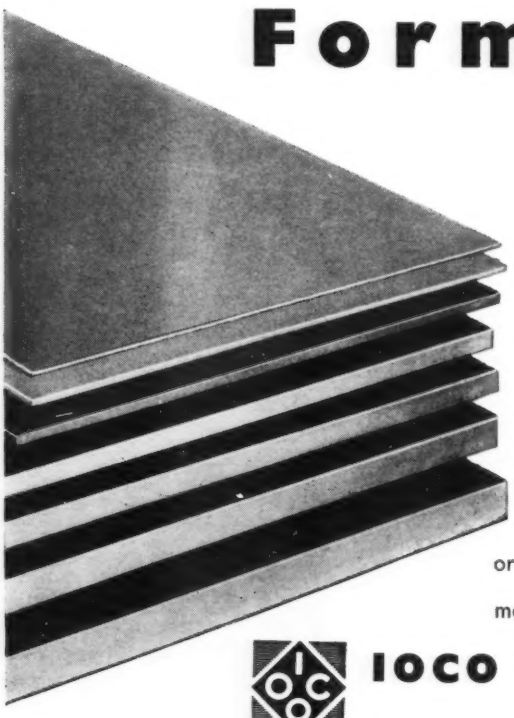
The
Mulberry Company
23a Sekforde St.
London, E.C.1
Tel. CLErkenwell 8356

Formapex

LAMINATED PLASTIC

for

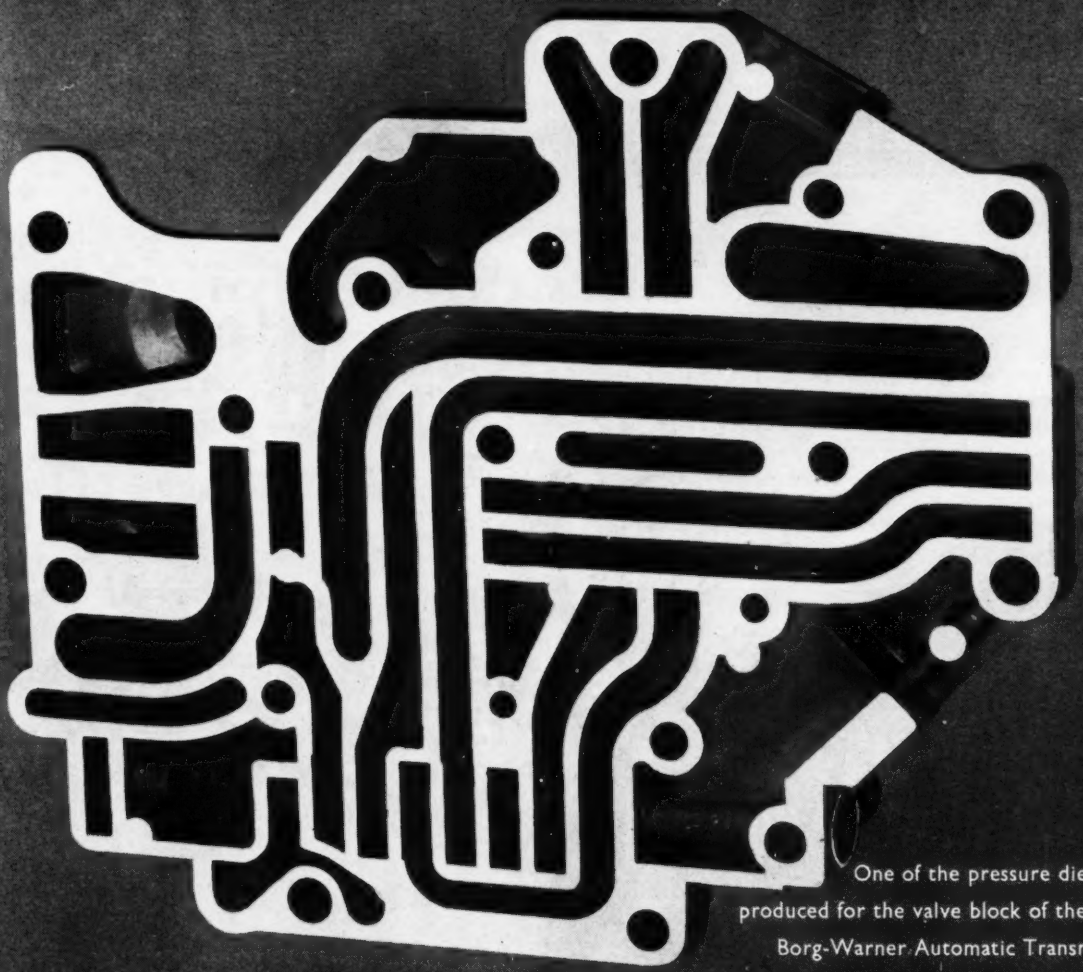
GEARS
BUSHES
WASHERS
COLLARS
BEARINGS
SMALL PARTS
JIGS



Fabric and paper base grades in machining and cold or hot punching qualities. High mechanical strength; low co-efficient of friction; resistant to heat, moisture, chemicals. Please write for Brochure 11K.

IOCO LIMITED
ANNIESLAND, GLASGOW W3
Telephone: Scotstoun 5501-6

For all pressure die castings



One of the pressure die castings
produced for the valve block of the
Borg-Warner Automatic Transmission

experience has shown . . .

Hiduminium

makes the most of *Aluminium*

HIGH
DUTY
ALLOYS LIMITED SLOUGH BUCKS

EMD 129 for further information

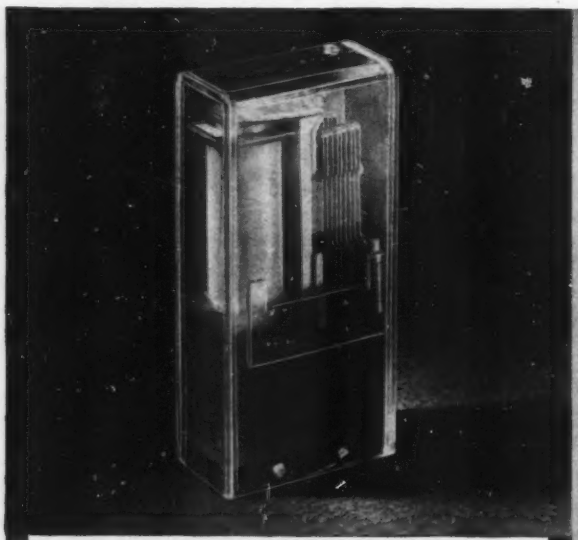
LONDON TRANSPORT CHOOSES

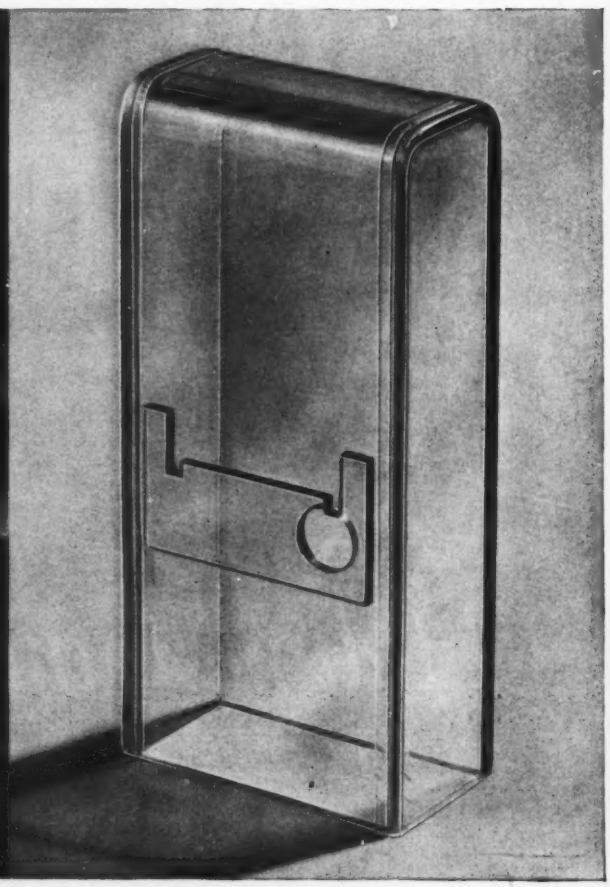
non-inflammable

COBEX

for sealed relays used with signalling

Because it is non-inflammable, as well as being transparent and a good electrical insulator, Cobex was chosen for a range of signal relays cases for London Transport. Safety and efficiency formed the basis for its selection, and the use of Cobex for these important components underlines why it is being specified in many industries where its unique combination of properties can result in safer and more dependable installations. Ask for publication No. 565 and technical Data Sheets.





Cobex

RIGID VINYL SHEET

a product of

BX PLASTICS LTD HIGHAM STATION AVENUE · LONDON E4

Subsidiary of The British Xylonite Co Ltd Telephone: Larkswood 5511

MATERIALS IN THE NEWS

Monthly Digest of Materials and Design News from Home and Abroad

Semi-conductor Materials

THE USE of ceramics in semi-conductor materials is possibly one of the most interesting developments in the field of materials for use in electronic equipment that has occurred in the last two years. The advantage of such materials lies in the fact that they will operate at high temperatures.

Thus, one new ceramic-type semi-conductor material developed by the Westinghouse Co. will operate, it is claimed, at reasonable electrical efficiencies at temperatures of from 1100 deg. C. up to 1480 deg. C.

The construction of such semi-conductor ceramic materials is based at present mainly on the use of common basic metal elements such as nickel, iron and magnesium. Other types of metal oxides are, however, being studied. At the same time, new types of semi-conductor materials based essentially on well-known compounds such as barium titanate and germanium are being investigated in the U.K. by a number of companies including the General Electric Co., Associated Electrical Industries Ltd., Standard Telephones & Cables Ltd. and Mullard Ltd.

Indeed, an entirely new use for germanium, which is at first sight quite divorced from that of its application as a semi-conductor material for electronic equipment, has been developed, according to the latest reports. This is the use of specially-purified germanium as a catalyst for chemical reactions of potential industrial importance. The use of the germanium for this purpose seems to depend on its preliminary exposure to a high-intensity electrical discharge.

The use of germanium in this manner is expected to be of particular interest in industrial chemical processes involving hydrogen. At the same time, the actual mode of operation of the germanium as a catalyst in the chemical experiments so far carried out and the temperatures involved, suggest that this development may well lead eventually to a widening of the potential scope of the use of germanium in electronics.

New Uses for Glass

GLASS—one of the oldest known industrial materials—is likely to find a wide range of new uses as the result of new U.K. and U.S. research which is currently in progress.

These new fields include the production of high-temperature-resistant tubes and nozzles, which can be cast or drawn to very fine tolerances, for use in guided weapons and in nuclear engineering, and the development of a series of new high-temperature-resistant protective glass coatings and cellular insulating glasses for structural use.

One new U.S. glass, designed as a lining material in chemical and other industrial equipment—which has recently been developed by the Pfaudler Co. in the U.S.A., is said to have a 30 per cent greater resistance to thermal shock than glasses of the same type hitherto available. It is claimed that it will withstand temperature differences between the walls of the vessel and that of the charge of chemicals contained within it of the order of 127 deg. C., when the vessel temperature is maintained at 121 deg. C.

Another recently developed 96 per cent silicon glass produced by the Corning Glass Works can be fashioned to tolerances of the order of 0.001 in. This glass has been specially developed for nozzles for welding equipment. The advantage of using glass for this purpose lies in the fact that it enables a close watch to be kept over the progress of the weld during precision welding. Other glasses of the same type which can be fabricated to even more precise tolerances are currently under development. Similar glasses are also being developed in the U.K.

One field in which much work has been undertaken in the U.K. is the investigation of glass manufacture and the composition of glasses by means of radioisotopes and gamma radiation. Techniques using gamma radiation are enabling the level of the glass in glass furnaces and feeders to be measured with extreme accuracy for the first time. Previously the high temperatures encountered made the undertaking of accurate measurements in these units impracticable. Research is also being carried out in the U.K. on the use of radioactive radiation in the manufacture of glass containers.

Radioisotope tracer elements have also been used to investigate the flow of glass in tank furnaces and to "label" sand so that it can be traced through the sand-washing and grading plants and during its passage through a glass melting furnace.

The results of these experiments are expected greatly to increase the accuracy with which glasses having special industrially desirable qualities can be produced and to enable new types of glasses for industrial use to be produced on a commercial scale with greater ease and—eventually—lower cost.

Experiments have been carried out to develop methods for detecting the presence of materials, such as selenium, which may cause radioactivity in the glass, so that measures for virtually eliminating such constituents from glasses designed for use in nuclear engineering can be developed. A number of new special glasses of this type have been produced recently by U.K. companies such as Chance Bros. and Optical Works Ltd.

Preventing Rubber Deterioration

THE FIRST chemical to be manufactured at the Wolverhampton plant of the Goodyear Tyre and Rubber Co. Ltd. is of particular interest. It is a colourless liquid anti-oxidant which can be used with both natural and synthetic rubbers and which does not, it is claimed, stain them.

The new compound is basically a styrenated phenol composition, viscous in form, which can be dispersed rapidly in both solid and liquid rubber compounds. At the same time, at temperatures above 25 deg. C., it can be added directly to the rubber stocks. Tests carried out with the new material are said to have shown that it is capable of bringing about considerable reductions in the extent of deterioration in both natural and synthetic rubbers due to weathering.

High-temperature Plastics

A NEW high-temperature-resistant plastics that is said to be capable of withstanding surface temperatures of the order of 1370 deg. C. has recently been developed for use in both guided weapons and in industry. The new material is a specially-developed laminate which is so designed that experimental tests are said to have shown that it conducts 25 per cent less heat than homogeneous plastics having a low rate of heat conduction.

Although the material has been primarily developed for the manufacture of outer coating of heat-resistant surface layers of military and industrial equipment, it is also said to have good physical strength and good resistance to attack by chemicals.

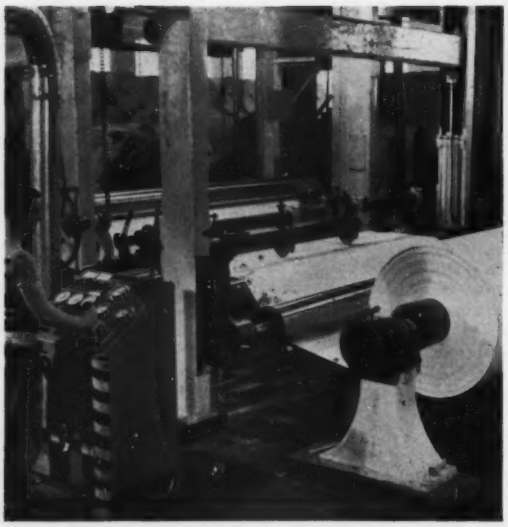
Details of the actual composition of the plastics laminate have so far been withheld, but experiments are known to be under way to determine and develop its industrial applications. These applications are likely to include its use as a surface layer material in the aircraft, guided weapons and chemical industries, as well as its use as a structural material in fields of engineering—particularly where high-temperature conditions, corrosion and physical strength are to be withstood.

PICTURE NEW

IN THE WORLD OF MATERIALS & DESI

GLASS FIBRE FOR NOSE CONE

Nose cone of the English Electric Thunderbird missile is of polyester-glass fibre to allow penetration by radar impulses and provide high strength. Here, a vacuum is applied to draw the Bakelite resin up through the glass fibre layer between the two moulds.



NO PAPER DUST WITH CARBIDE CUTTERS

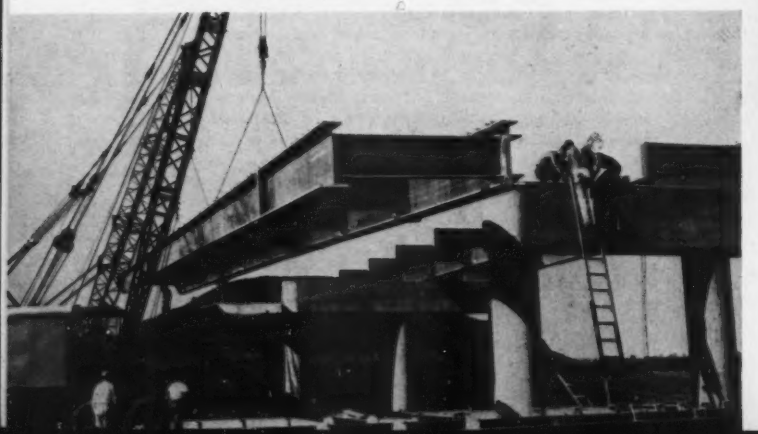
Cemented carbide instead of steel for blades used by the Lee Paper Co. in the U.S.A. on a paper-cutting machine eliminated the problem of cutting-dust and reduced maintenance to a spectacular degree. With steel upper blades operating against cemented carbide bottom slitters, there is a constant honing action that resharpens the steel blades.

STEEL SHELLS FOR NUCLEAR STATION

Left: Sections, which will be welded together on site to form shells for steam-raising units at the Hinkley Point nuclear power station, standing in the assembly line at a Renfrew factory. The station is being built by the English Electric, Babcock & Wilcox, Taylor Woodrow Atomic Power Group.

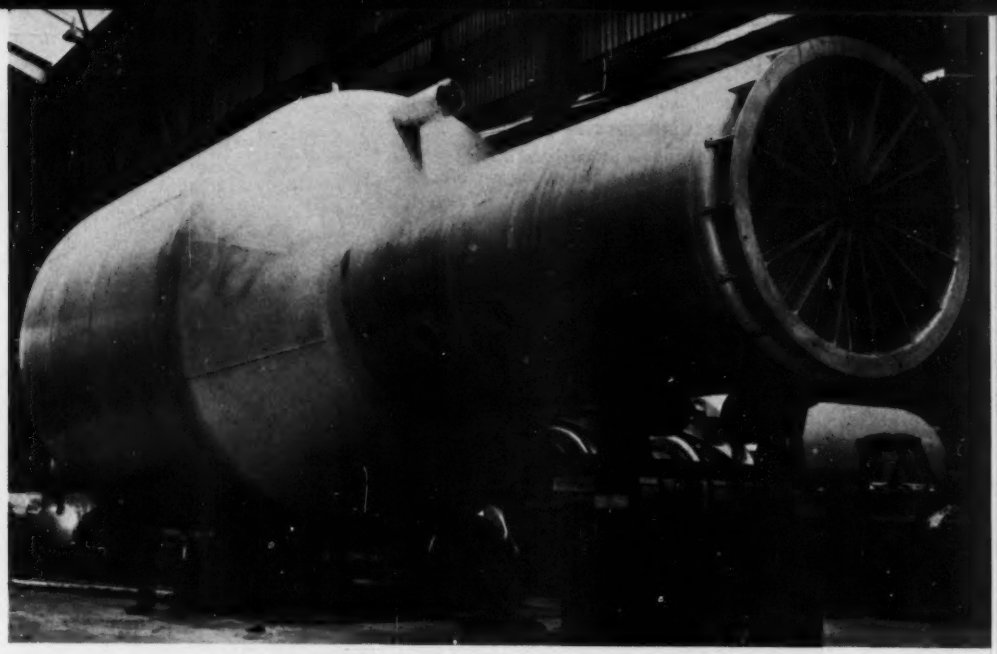
GIANT ALUMINIUM BRIDGE ASSEMBLY

Below. A giant sub-assembly of aluminium bridge members is lifted into position during construction of the first aluminium girder-type road bridge in the world near Des Moines, Iowa. Prefabrication of the members speeded construction, which was sponsored by the highway authority jointly with the Aluminium Co. of America, Reynolds Metals Co. and Kaiser Aluminium & Chemical Group.



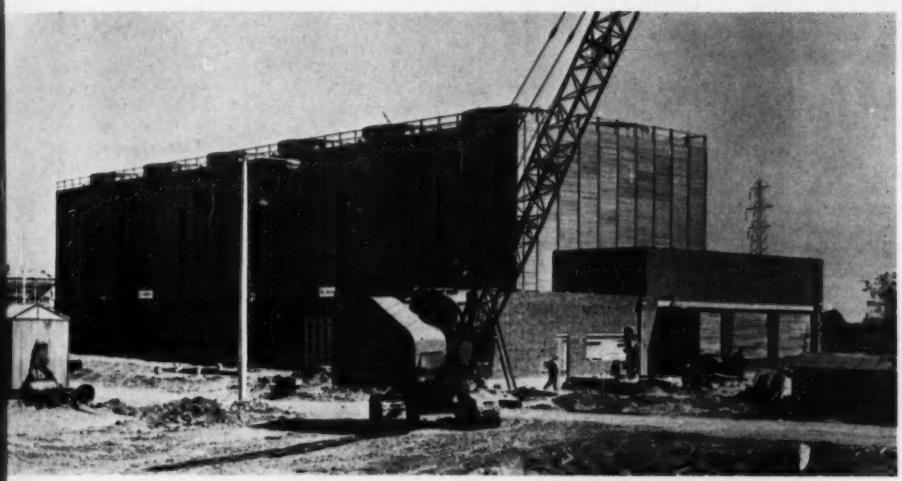
AMPHIBIOUS HELICOPTER

The Sikorsky S-62 is claimed to be the first amphibious helicopter with a flying boat type hull suitable for operating from water, land, ice, snow or swamp. This type of hull weighs less than a land-type hull fitted with inflated pontoons. It also eliminates much of the drag associated with pontoon-type flotation both in flight and afloat.



ALUMINIUM REACTOR CORE TANK

This Merlin-type reactor core tank has been argonaut welded in 99.5 per cent and the re-entrant tubes in 99.8 per cent purity aluminium by the A.P.V. Co. Ltd., to the order of the A.E.I.-John Thompson Nuclear Energy Co. Ltd. for the North Rhine Westphalia government. The reactor is of the swimming pool type.



TIMBER COOLING TOWER

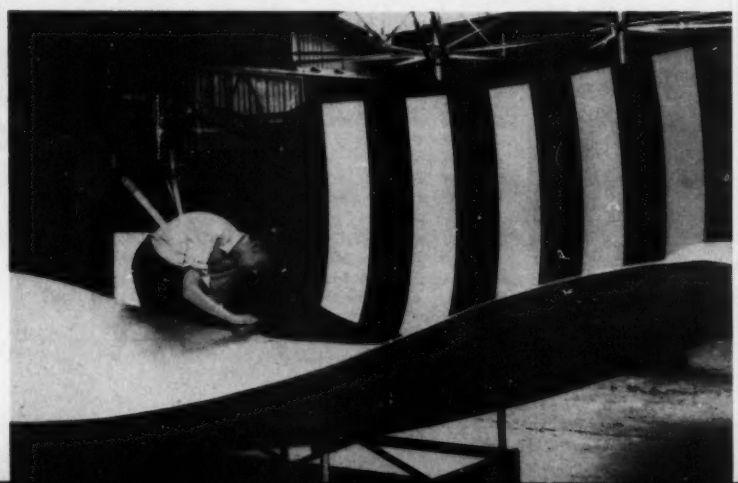
Timber induced-draught cooling tower designed and manufactured by Head Wrightson Processes Ltd. for the Rolls-Royce aero engine altitude test plant. This tower is capable of carrying out the task of cooling 1.8 million gallons of water an hour.

GLASS FIBRE FIRE TENDER

A polyester-glass fibre hard top is fitted to the body of the Austin Gypsy fire tender shown at the Commercial Motor Show this year. It has a Coventry Climax front-mounted pump with a pumping rate of 500 galls./min. at 100 p.s.i.

DIFFICULT MOULDING CONTOURS

Final finishing of the Cossor CR.21 radar reflector, based on polyester resin, which is produced on a compound curvature mould resurfaced with Bakelite epoxide resin. Mould release is exceptionally good in spite of difficult contours. The finished product has very accurate dimensional stability.



Design for Commercial Vehicles

MANY of the exhibits at this year's Commercial Motor Show indicated a break with tradition for a more scientific approach to design problems.

Air suspension was of particular interest and, from many vehicles using this system, it is evident that its use, replacing conventional springing, will extend quickly beyond the motor industry. Rubber mountings in the past have been particularly important where low frequencies are encountered, but air springing is able to accommodate even lower ranges.

A notable design feature was the simple and ingenious chain tensioner by Renold Chains Co. A neoprene-based rubber block is held in rolling contact with the chain by oil pressure from the normal feed system; as the chain stretches, a spring adjusts the block to take up the slack. This device, which has been proved to have a long life and quietness in operation, should have a wide field of applications.

Dunlop Rubber Co. showed for the first time solid tyres made from Duthane, a synthetic material based on polyurethane. These are intended for trucks with high loadings for short periods, and where high resistance to oil and grease is needed.

Less Russian Aluminium

IMPORTS of Russian aluminium into the U.K. are to be restricted during the next twelve months, by a Soviet agreement with the Board of Trade, following complaints from the Aluminium Co. of Canada of dumping in Britain (this page, last month).

The Soviet authorities have undertaken not to export in the coming year more than 15,000 tons, which is slightly less than the 1957 figure.

New Extrusion Technique

AN INTERESTING experiment in extruding metals which may have wide possibilities of application in the future was mentioned recently during the Golden Jubilee autumn meeting of the Institute of Metals. The process involves two opposing rams which cause the slug or calot to flow around the ram bodies to produce a tubular section with an internal diaphragm.

The technique is understood to have been originally developed for assessing the possible production of gudgeon pins, but it already seems to be offering considerable scope in the production of short tubular members at a high rate.

Measuring Fatigue

RESEARCH into techniques for measuring the fatigue of metals while they are actually in use has received much attention in the U.K. since the crash of the two Comet Mk. I aircraft in 1955.

One method of doing this is to measure the way in which the metal parts of, say, the aircraft or the industrial flywheel, or machine are vibrating or responding to the treatment they are receiving during operation. Most types of equipment which are capable of measuring vibration can only do so through using a "pickup" probe which must be attached to the part under investigation. The attachment of such a probe inevitably, however, affects the extent and occurrence of the vibrations and therefore limits the usefulness of the measurements achieved.

A new British device developed by Wayne Kerr Laboratories overcomes this problem, however, by using a probe which need not be placed in contact with the surface of the metal, yet it can measure the changes in frequency of vibration which occur with exceptional accuracy. At present the device, which is now nearing the production stage, is being used primarily for experimental work on guided weapons structures and certain specialised types of industrial equipment. The work carried out so far has indicated that with some further development, the equipment could be used to maintain a continuous check on the vibrations occurring in aircraft during flight.

The operation of the system depends on the use of a special kind of electrical bridge—the transformer bridge.

IN NEXT MONTH'S ISSUE . . .

Principal feature articles in the December issue of ENGINEERING MATERIALS AND DESIGN will include:

Mechanical Stepless Transmissions
Self-contained units and devices employing belt drives.

Nylon in Engineering
Properties and applications, particularly for gears and bearings.

Asbestos in Missiles and Aircraft
An answer to many design problems involved in high-speed flight.

Stainless Steel as a Structural Material (Part 2)
Evaluation of properties and characteristics of these metals.

Sintered Alumina Cutting Tools
Assessment of the present trends and future possibilities.

Design of Simple Heat Exchangers
Practical application of heat flow and rate of heat transference calculations.

Inorganic Insulation Developments

THE DEMAND for materials with better resistance to heat than organic insulations has led to some interesting developments in the use of inorganic phosphates, but the latest information concerns a new range of chemicals called phosphor nitriles, which have been developed by the research department of Albright & Wilson Ltd.

Unlike organic materials which are built up chemically on a carbon chain, these new materials are built up on a structure consisting of alternate atoms of phosphorus and nitrogen. A large range of materials based on this structure is theoretically possible and already applications have been reported involving polymerised phosphonitrilic chlorides. Other synthetic resins and plastics have been produced from combinations of phosphonitrilic chlorides with organic chemicals.

These new materials have very great resistance to heat on account of the stability of the P-N skeleton. Two further materials having good insulating properties and suitable for operation at extremely high temperatures are boron nitrides and silicon nitrides. Information from the Carborundum Co. of the U.S.A. indicates that these materials are both capable of operating at temperatures over 1,000 deg. C.

Vermiculite in Heat Insulation

NEW DATA about the performance of exfoliated vermiculite for use in heat insulation has recently become available as the result of experiments carried out at the U.K. National Physical Laboratory and at the Forschungsheim Fur Warmeschutz, Munich, one of West Germany's leading research centres.

The data resulting is the most comprehensive analysis of performance of this material for thermal insulation so far made available. Its particular importance to potential users of this material lies in the fact that the experiments have shown that density plays an important role in performance at temperatures of over 93 deg. C.

At these higher temperatures the density of the material becomes very important—the denser samples (which are also of a smaller grade) apparently giving "strikingly better results." This fact had not been fully realised before these experiments were carried out. At temperatures lower than 93 deg. C. the larger grade, lighter, vermiculite gave far better performance—a fact already well known.

Exfoliated vermiculite is primarily used in domestic furnaces and cold store insulation and packaging.

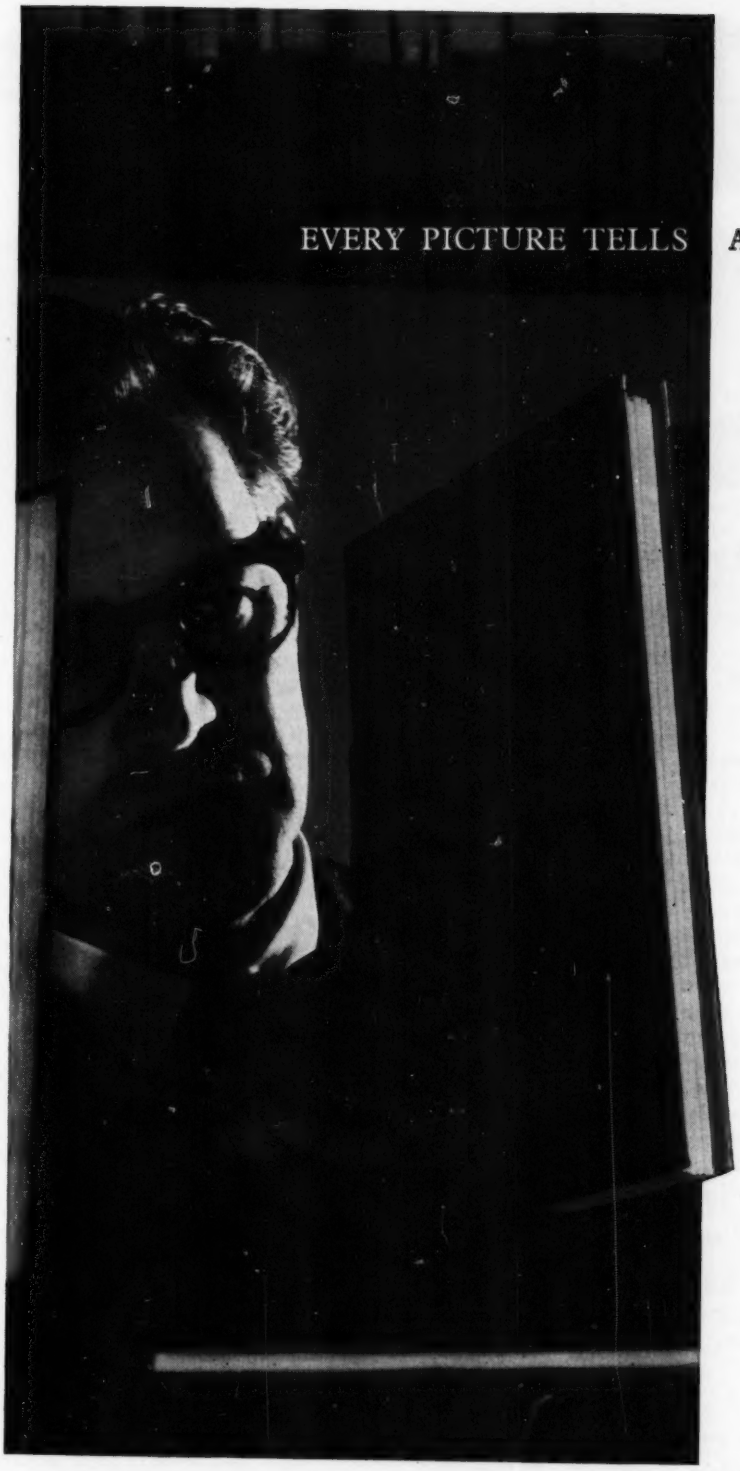
Silicon—For Electronics and Engineering

SILICON now shows promise of becoming an important engineering material as well as a material for use in the construction of electronic equipment.

Recent research which has been carried out under the sponsorship of the Ministry of Supply in the U.K. and by the Union Carbide Corporation in the U.S.A. has shown that silicon compounds can be used to produce protective coatings capable of withstanding temperatures of the order of 1480 deg. C., and at the same time giving excellent protection against attack by chemical compounds, particularly acids.

Ziegler Plastics

PLANS for the production of polyethylene at Grangemouth are being prepared by an associated company of the Distillers Group and not, as indicated last month, by the Shell Chemical Co.



EVERY PICTURE TELLS A NICKEL STORY

He seeks enlightenment—and whether his eyes are on distant projects of research or the daily problems of an industry, his basic needs are the same. Exactness. Facts that work. Ideas that will help him to the goal. If his work involves the choice of metals for new and exacting conditions, sooner or later his search will bring him to nickel. Mond have the resources for research and development and supply technical publications for guidance in the choice and use of modern materials.

Enough Nickel for all needs—

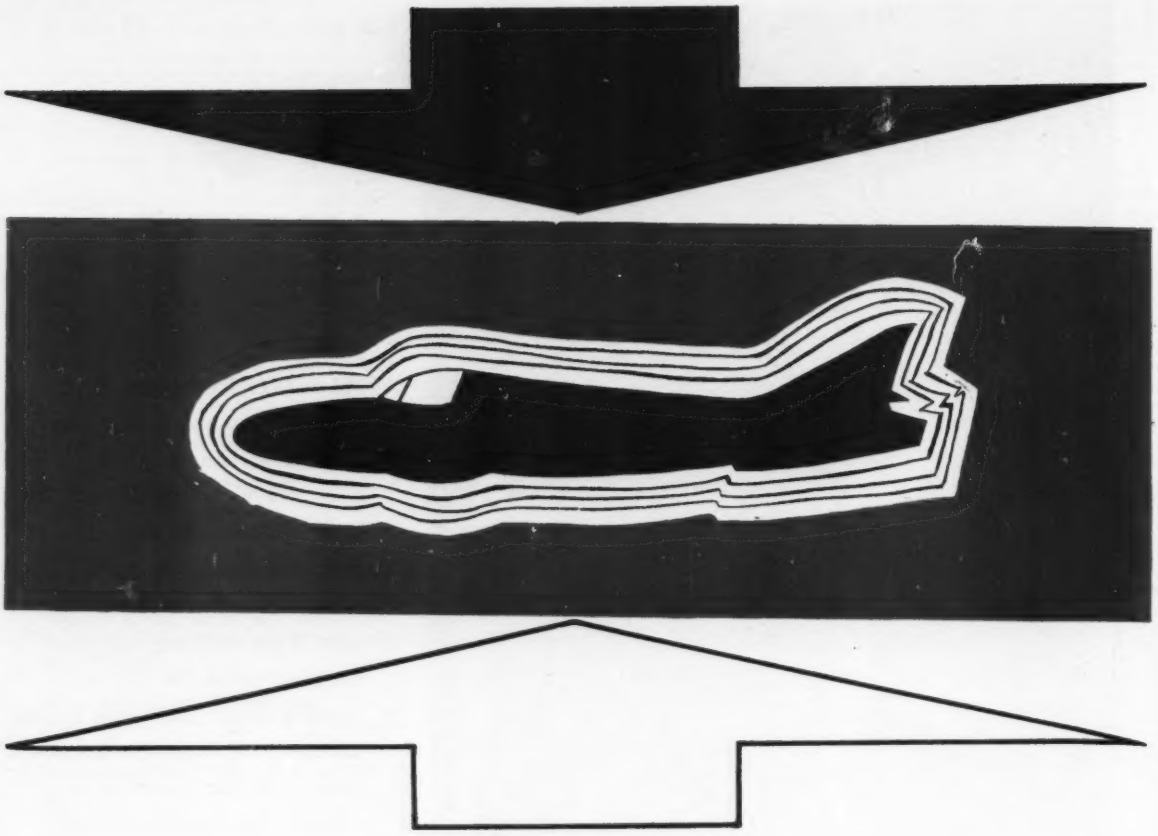
Plan ahead with **MOND NICKEL**

THE MOND NICKEL COMPANY LIMITED, THAMES HOUSE, MILLBANK, LONDON, S.W.I

TGA GH28

November, 1958
G

05



The new cost-cutting factor in tool production

Press tools of various types, as well as drill jigs, foundry patterns and vacuum forming moulds can be quickly, accurately and simply produced from "Epikote" Resins—instead of metals. Accuracy is ensured by their very low shrinkage on cure. Casting is simple, and is carried out at low temperatures; subsequent machining and finishing are seldom necessary.

Think of the savings in time and cost!

Other advantages are weight savings up to 80 per cent, excellent corrosion and chemical resistance, and easy repair.

Ask for details of these important developments quoting No. EE3.

EPIKOTE EPOXY RESINS

SHELL CHEMICAL COMPANY LIMITED. *In association with Petrochemicals Limited and Styrene Products Limited.*
Divisional Offices: LONDON: Norman House, Strand, W.C.2. Tel: TEMple Bar 4455. BIRMINGHAM: 14-20, Corporation Street, 2. Tel: Midland 6954-8. MANCHESTER: 144-6, Deansgate. Tel: Deansgate 6451. GLASGOW: 124, St. Vincent St., C.2. Tel: Glasgow Central 9561. BELFAST: 35-37 Boyne Square. Tel: Belfast 26094. DUBLIN: 53, Middle Abbey Street. Tel: Dublin 45775.

"EPIKOTE" *is a Registered Trade Mark*

Engineering Materials and Design

NEED FOR MATERIALS SPECIALISTS

A PROBLEM constantly on the minds of progressive industrialists and educationists is the widening gap between the vast and ever-growing number of materials available to the engineering industry and the means of providing designers and other engineers with the knowledge that will enable them to take full advantage of those materials.

The seriousness of the problem cannot be underestimated. No thoughtful engineer could disagree with Sir Willis Jackson, F.R.S., director of research to the Metropolitan-Vickers Electrical Co. Ltd., who, in one of his lectures, has defined engineering as the exploitation of the properties of materials, adding the view that "the possibilities of progress in many branches of engineering are bound up in the most intimate manner with the improvement of well-established materials and the discovery and development of new ones". It goes without saying, of course, that the possibility of progress only becomes a reality where designers and engineers are well informed about the new and improved materials and have some incentive to use them.

One has only to survey the engineering developments of the past few years to realise how true this is. The nuclear power programme owes as much to the successful application of such materials as uranium, graphite, aluminium and steel as to the fundamental knowledge of nucleonics, and further advances in this field will no doubt depend on the development of such metals as zirconium and beryllium.

This is however, a special case, and there is not much ground for criticising such sectors of industry as far as the study and use of materials is concerned. What is much more important and much less satisfactory is the position in which the general run of engineering firms find themselves when it is a question of selecting and applying materials. Replies to a survey recently made by ENGINEERING MATERIALS AND DESIGN have underlined the weaknesses of the engineering industry and the educational system in this respect and have also emphasised the economics as well as the technical necessity of taking remedial action. In heavy engineering, the major cost of apparatus lies in the materials, and in light engineering, where outputs may be very great and competition severe, a decimal point saving in materials costs is welcome, even though that element in cost is a small part of the whole. In some quarters the view is expressed that in this country, in design, we have not been as conscious as continental engineers of the necessity of saving materials.

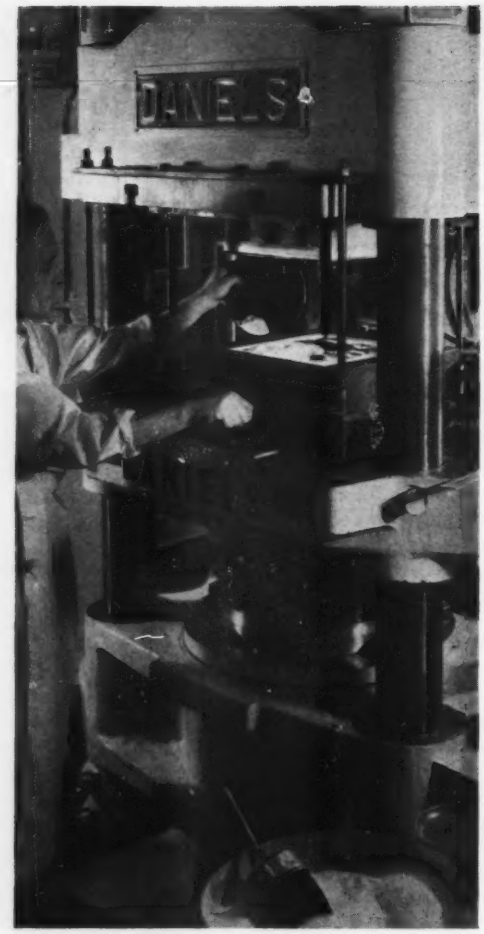
Many of those who took part in our survey have commented on the situation as they know it in various industries. The picture is not, of course, one of unrelieved gloom. There are signs that industry as a whole is beginning to realise the importance of the study of materials as a subject in its own right, and some organisations not only try to keep their designers up to date in materials but appoint specialists to advise on the properties and applications of materials. In the absence of men trained specially to meet the requirements of engineering, the position of materials specialist is often given to a metallurgist or chemist whose knowledge is too academic and not sufficiently up to date. A materials specialist in engineering does not need to know a great deal about the extraction and refining of metals or the manufacture of plastics, but he should have had a basic training in engineering design principles and be able to read a drawing.

There is a fairly general agreement about the steps that should be taken to put this vital part of the engineering house in order. Some universities, such as Cambridge and Birmingham, give a fair share of lecture time to materials in their mechanical engineering courses, but in some institutions there is scope for improvement, in spite of obvious difficulties in cramming more teaching into already overloaded syllabuses and in constantly changing them to keep pace with the fast-moving developments in materials.

There are difficulties, too, in recruiting sufficient teachers with the necessary knowledge. A partial solution might be the overhaul of existing syllabuses, after consultation between education authorities and industry. A more promising line of attack is the more regular exchange of staff between colleges and industry, so that courses could be kept up to date and men in industry with a special knowledge of particular materials should be encouraged by their employers and the education authorities to give part-time lectures. A number of universities and colleges are trying to cater for the materials specialist by means of postgraduate courses, but so far the response of industry has been disappointing.

The recently published University Grants Committee's report appeals to the universities to adopt a liberal policy in admitting to postgraduate study men whose qualifications have been gained elsewhere. It is to be hoped that the Government's lead in encouraging postgraduate work will be actively supported by the engineering industry.

The effective use of engineering materials may well be one of the chief factors in Britain's future prosperity, and the proper training in this subject of the men who design and build engineering products demands urgent attention.



Moulding sheets of p.t.f.e. at the North London factory of Siemens Edison Swan Ltd.

P.T.F.E. FOR SPECIAL ENGINEERING PURPOSES

Although many engineering designers are familiar with the properties of p.t.f.e., they may not be fully aware of the wide scope for application of this interesting material. This article is an up-to-date account of the present techniques in applying it to modern engineering problems

by D. A. SMITH, M.Sc., A.R.I.C., A.I.R.I., A.N.C.R.T.*

AMONG the great variety of plastics materials available today and in increasing use in industry, polytetrafluoroethylene is unique in many aspects. Not only are the properties of its fabricated components markedly dependent on processing methods and conditions but the properties of the raw material are so unusual that the processing methods themselves differ very much from those used for other plastics materials, being in some ways more akin to the methods of powder metallurgy.

P.t.f.e. has proved of great interest to the engineer, but the actual amount used, less than 200 tons per year in the U.K., gives but a poor indication of its utility in a wide range of applications. Methods of preparation have been described in the literature.[1, 2] The principal raw material suppliers are E. I. Du Pont de Nemours and Co. in the U.S. under the name of Teflon and I.C.I. Ltd. in the U.K. under the name of Fluon. There is a small quantity produced elsewhere, for example, by Farbwerke Hoechst A.G. in West Germany (Hostaflon TF) and in Russia (Ftoroplast-4).

The principal grades of p.t.f.e. are known as granular polymer, dispersion powder, and dispersion fluid.

Granular polymer is the general purpose material initially fabricated by moulding or extrusion; the other grades have been introduced to suit special fabrication techniques or to obtain certain improved properties.

GENERAL PROPERTIES—The properties of p.t.f.e. are well known and so need little discussion in this paper. Chief among them are: good thermal stability, inertness to all commonly encountered chemicals and solvents, excellent electrical properties, generally good mechanical properties and a very low coefficient of friction. The material shows no tendency to adhere to many conventionally "sticky" materials such as doughs, glues, resins, ceramic clays, etc., and so finds application in plant handling such materials.

ENGINEERING PROPERTIES—These are summarised in Table 1 but the figures quoted should only be taken as a general guide to be read in conjunction with the text. This is because the effects of fabrication on the properties of p.t.f.e. are of importance[5] and, in addition, the properties themselves sometimes show anomalous temperature dependence within the range of service temperature, e.g., the expansion of p.t.f.e. has been studied by Kirby[6] over the range −190 deg. C. up to +300 deg. C. and Fig. 2 shows the type of behaviour observed.

Some grades of the polymer are supplied compounded with fillers such as graphite or glass fibre to reduce creep and to improve heat transfer. Such compounding reduces volume cost of the material but usually has a deleterious effect on mechanical properties.

Basic Processing

The fabrication of p.t.f.e. articles usually involves two basic operations, compression of the raw material into the desired shape, followed by a sintering operation carried out at a sufficiently high temperature to allow the polymer particles to fuse together into a more coherent form.

* *National College of Rubber Technology.*

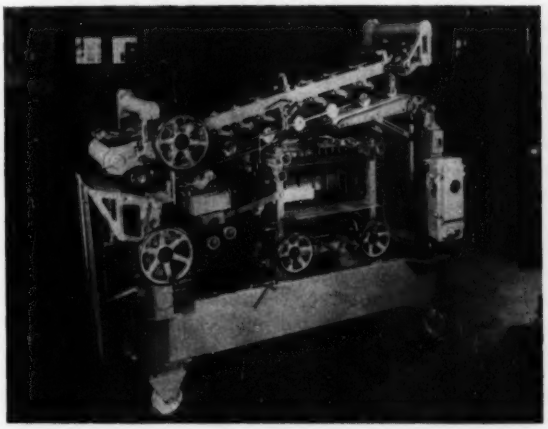
During sintering, toxic fluorocarbons are evolved and efficient ventilation of the oven is therefore necessary.

COLD MOULDING—Normally, compression of the p.t.f.e. powder is carried out cold in positive compression moulds at pressures of 1500 up to 3000 p.s.i. Lower pressures may lead to porosity and higher pressures to cracking of the preform during later treatment on account of distortion. The preform is sintered in an oven at 360 deg. C. for up to three hours, the operation being complete when the moulding becomes translucent. During sintering, shrinkage occurs principally in a plane at right angles to the direction in which the pressure was applied during preforming (see Fig. 3).

Results of an investigation by Chapman and Bunn[7] showed that:

(i) Variation in preform pressure over the range 2000 to 6000 p.s.i. accounted for 50 per cent of the total variation in dimensions of the mouldings; cooling rate variation accounted for 25 per cent; sintering time ca. 15 per cent. Dwell time and heating rate had minor effects; ram speed, no notable effect.

(ii) A set of curves could be constructed which might be used by the designer to predict mould shrinkage.



Fluon p.t.f.e. coating was applied by Durable Plastics Ltd. on the feed plates of this Pindy labelling machine to prevent labels sticking to feed plate fingers.

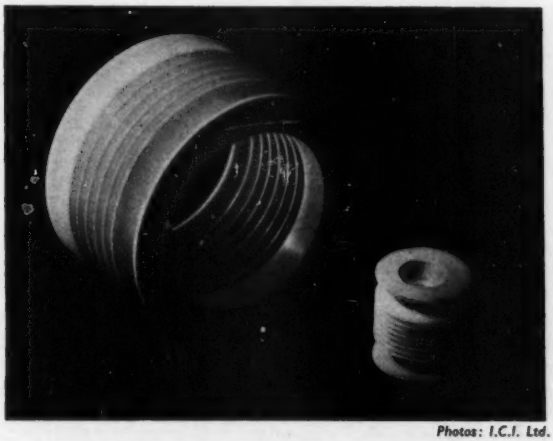
(iii) For free sintered 1 in. test cubes, a suitable tolerance perpendicular to the direction of mould opening was ± 0.006 in. and parallel to the direction of opening ± 0.010 in. The chief factor in maintaining these tolerances on a production run was the use of weight mould feeding rather than volumetric feeding.

While the effects of preform pressure and sintering time are not difficult to understand, the effect of cooling rate is more complex. Slow cooling promotes crystal growth giving rise to a denser material and so reducing all dimensions. However, internal moulding stresses are also relaxed and this may be the greater effect, leading to an increase on cooling of the dimension which was compressed during preforming. Distortion of flat surfaces is also an important factor and to minimise this it is usual to cool slowly from 220 deg. C. down to 130 deg. C., below which temperature the rate of cooling may be increased.

IMPACT MOULDING—While cold moulding followed by free sintering is satisfactory for most small articles, difficulties arise with mouldings having minimum dimensions greater than 1 in. since they develop cracks on cooling due to poor heat transfer. The effect can be minimised by pressure sintering in the mould under a pressure of ca. 2000 p.s.i. down to at least 250 deg. C.

Mouldings with deep-draw recesses or large changes in cross-section are not easily produced by these techniques and a modified impact moulding ("coining") method may be used. A cold preform is made, it is sintered at 360 deg. C. and allowed to cool to about 315 deg. C. (just below the transition point); it is then placed in a cold finishing mould and pressed. The method makes use of the cold flow property of the sintered plastic to attain the final dimensions. Metal inserts are often incorporated in impact mouldings after final pressing by merely forcing the inserts into moulded holes giving an interference fit and relying on the elastic memory to maintain a tight grip.

EXTRUSION METHODS—As an alternative to compressing the powder into a moulding preform by means of a ram, the compacted material may be forced through a die to form a rod or pipe. The ram extruder operates on dispersion polymer which has been mixed with a quantity (18-20 per cent) of oil to act as a lubricant and then preformed into a loose slug under low pressure. The extrusion is passed through an oven to flash off the lubricant after which it is free sintered. Difficulties in maintenance of dimensions have been met particularly at points corresponding to the return stroke of the ram. Ram pressures are high (up to 10,000 p.s.i.) and it is claimed that sections from 0.004 in. up to 0.250 in. can be extruded easily at a rate of 20 ft/min. The process has been described fully in the literature[9] and it is best adapted to the production of tapes, thin walled tubing, covered wire and monofilament, the products being characterised by excellent resistance to flex fatigue.



Photos: I.C.I. Ltd.

Expansion bellows manufactured from Fluon p.t.f.e. by Crane Packing Ltd.

Heavier sections are less easy to produce by this method and recourse is made to quasi-conventional equipment in the screw extrusion of granular p.t.f.e. powder.[10] In fact, this technique consists of a continuous moulding operation in which loose powder, which has previously been sintered and then deaggregated in a separate unit, is conveyed by the screw to a long tubular die. The last few flights of the screw compact the polymer into the die which is held at about 360 deg. C. Careful control of the distribution of free powder in the die before compression and of the temperature gradient (cooling) from the die is necessary to prevent cracking of the extrudate. Considerable diametral shrinkage (from 12.5 to 18.4 per cent) occurs on cooling from sintering to room temperature. While slow in comparison with other plastics extrusion processes, extrusion rates are adequate for the small production normally required. The following figures[11] are quoted for a 1 in. extruder at a screw speed of 30 revs./min.

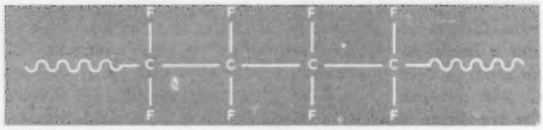


Fig. 1. Chemical structure of p.t.f.e. It consists of long chains of carbon atoms, each of which carries two fluorine atoms, which are largely responsible for the materials unique properties.

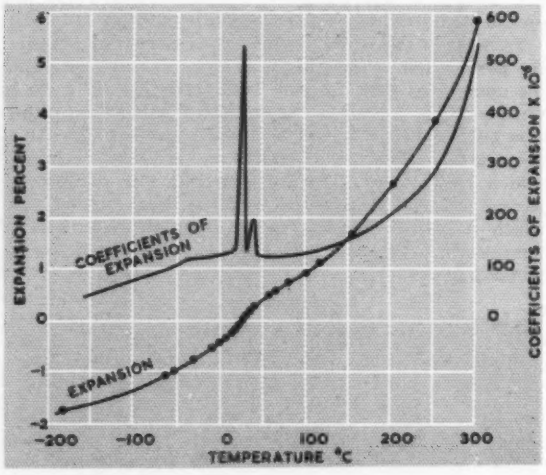


Fig. 2. Anomalous expansion behaviour of p.t.f.e.

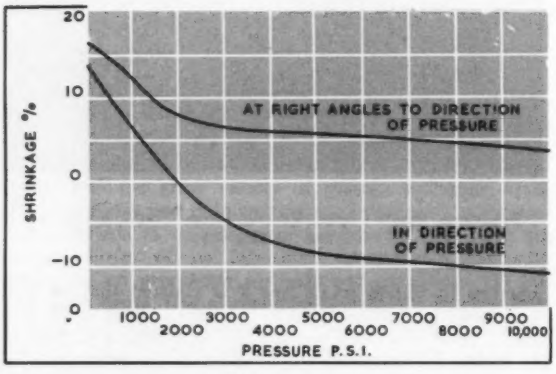


Fig. 3. Variation of shrinkage with preforming pressure on sintering.

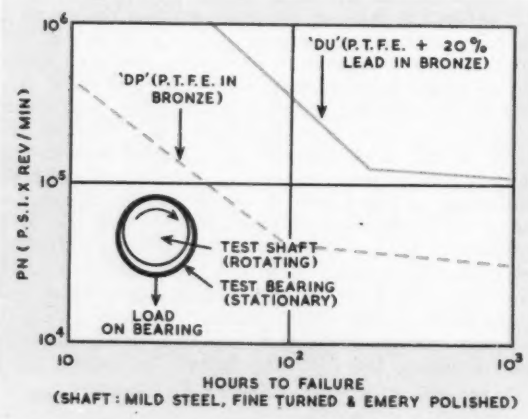

PN (P.S.I. X REV/MIN)
'DP' (P.T.F.E. IN BRONZE)
'DU' (P.T.F.E. + 20% LEAD IN BRONZE)
TEST SHAFT (ROTATING)
TEST BEARING (STATIONARY)
LOAD ON BEARING
HOURS TO FAILURE
(SHAFT: MILD STEEL, FINE TURNED & EMERY POLISHED)

Fig. 4. Bearing performance of bushes (unidirectional loading).

Product	*Extrusion rate (in./min.)*
Rod $\frac{1}{16}$ in. diameter	5
Rod $\frac{1}{2}$ in. diameter	$2\frac{1}{4}$
Tube $\frac{1}{4}$ in. o.d. × $\frac{1}{2}$ in. i.d.	3

The difficulties of extruding the normal grades of p.t.f.e. have led to the development of special easy processing copolymers such as Teflon 100-X[12] but a British equivalent has not yet made its appearance.

Standard Shapes; Further Processing

The products of basic processing are currently available in the forms of rods, tubes, sleeves, discs, rings, sheets, cord, tape and covered wires.

More complex forms can be produced by three main methods: (a) Basic processing operations using special moulds or dies, (b) Machining a suitable standard form, (c) By means of a further plastics processing operation.

The use of special moulds has much to commend it if production quantities of gland packings, etc., are required and the leading component suppliers maintain numbers of such moulds. For trials or small quantity production of development items, machining avoids the initial mould cost and has the additional advantage of holding closer dimensional tolerances than can be obtained by moulding.

MACHINING—P.t.f.e. is machined easily in most operations, best results being obtained by using high cutting speeds, deep cuts and clean edge blades, the machine settings being, broadly speaking, as for free cutting brass.[4] No coolant is required. The following recommendations may be taken as a general guide:[3]

Turning: Surfacing speed 60-120 ft./min.
Feed up to 0.1 in. per revolution
Depth of cut up to 0.1 in. (up to this limit, the deeper cuts give the cleaner finish)
Top rake of tool 16 deg., front rake 5 deg.

Drilling: $\frac{1}{4}$ in. hole, 1000 rev./min.
$\frac{1}{2}$ in. hole, 600 rev./min.
(Standard twist drills ground at conventional angles are satisfactory)

Milling: Conventional high speed routing equipment.

Hand operations: Normal wood-working tools can be used.

Edge burrs can be removed with fine glass-paper or with a sharp knife and a fine finish can be obtained by hand honing or, for some grades, by use of a lapping machine. No smoking is allowed during p.t.f.e. machining operations since the dust will decompose in contact with the lighted tobacco giving rise to toxic products.

A standard form which is produced by machining is p.t.f.e. tape. The narrower tapes are produced by "veneering" from a cylindrical block while the wider films are made by a "slicing" technique, which limits the length of each sheet. The elongation at break of the film is often improved by heating to about 400 deg. C. followed by immediate quenching in a cold water bath. By this means the EB value can be raised from 150 per cent to about 400 per cent. If the product is now cold rolled to about one third of its original thickness, the elongation at break is reduced to about 50 per cent but the tensile strength is raised from about 2000 p.s.i. to about 12,000 p.s.i. Different combinations of mechanical properties can be obtained by rolling the film to any intermediate degree, but the products become unstable at elevated temperatures and tend to revert to their original thickness.

Swarf from machining may be remoulded if sufficiently clean, but it is more usually employed for gland and filter packings; gland packing materials can also be produced in a flake-like form by excessive cold rolling of film.

TABLE 1. Some engineering properties of p.t.f.e.

PROPERTY	UNITS	METHOD OF TEST (where stated)	REFERENCE (1)	(2)	(3)	(4)
Specific Gravity			2.1-2.3	2.2	2.1-2.3	2.1-2.2
Specific Volume	cu. in./lb.		—	—	13.2-12.1	—
Tensile Strength	lb./in.²		1,500-2,000	1,500-2,500	1,500-2,000	2,000
Tensile Strength (oriented sheet)	lb./in.²		up to 12,000	10,000-15,000	—	—
Elongation at Break	%		50-400	50-400	20-100	100
Youngs Modulus	lb./in.²		0.6×10^5	0.58×10^5	0.58×10^5	0.58×10^5
Flexural Strength	lb./in.²		—	—	1,600	—
Flexural Strength	lb./in.²	A.S.T.M. D790-49T at 73° F.	—	—	—	did not break
Compressive Strength	lb./in.²		—	—	1,700	—
Stiffness	lb./in.²	A.S.T.M. D747-50 at 73° F.	—	—	—	$0.5\text{-}0.9\times10^5$
Impact Strength	ft. lb./in. notch	Izod	Approx. 4.0	4.0	2.5-4.5	4.0
Hardness		Shore A	Approx. 100	—	—	—
Hardness		Shore D A.S.T.M. D676-49T	55-70	—	—	50-65
Hardness		Brinell	1-2	—	—	—
Coefficient of linear thermal expansion:		A.S.T.M. D696-44				
per °F.		in temp. range 73-140° F.	—	—	—	5.5×10^{-5}
per °C.		in temp. range 25-100° C.	9.9×10^{-5}	—	—	—
Coefficient of cubic expansion		in temp. range −40 to +300° C.	—	$25\text{-}45\times10^{-4}$	$15\text{-}35\times10^{-4}$	—
Thermal Conductivity	cals./sec./cm.²/°C./cm.		—	5.8×10^{-4}	6×10^{-4}	—
Thermal conductivity	B.T.U./hr./sq. ft./°F./in.	Cenco-Fitch, 0.18 in.	—	—	—	1.7
Specific Heat	B.T.U./lb./°F.		0.25	—	0.25	0.25
Deformation under load	%	A.S.T.M. D621-51, 1,200 lb./in.²/24 hrs./122° F.	—	—	—	4-8
Deformation under load	%	A.S.T.M. D621-51, 2,000/lb./in.²/24 hrs./122° F.	—	—	—	25
Heat Distortion Temp.	°F	A.S.T.M. D648B-45 T, 66 lb./in.²	—	—	—	250
Maximum Service Temp.	°F		480-570	480-570	480-570	480-570
Volume resistivity	ohm-cm.		$10^{19}\text{-}10^{21}$	10^{19}	10^{17}	$10^{19}\text{-}10^{21}$
Dielectric Strength	volts/mil.		400 (a)	1,500-1,800(b) 500(c)	500 (c)	200 KV/cm.
Dielectric Constant		$10^2\text{-}10^6$ cycles/sec.	—	2.0	2.0	2.0
Surface Arc Resistance	sec.	A.S.T.M. D495-48T	Does not track	>100	>200	Does not track
Surface Resistivity	megohms	A.S.T.M. D150-52T, 100% R.H.	—	—	—	3.6×10^6
Permittivity		60 up to 10^6 cycles/sec.	2.0	—	—	—
Power Factor	tan δ	60 up to 10^6 cycles/sec.	0.0001	0.0001	0.0001	0.0001
Water Absorption	%	A.S.T.M. D570-42	<0.01	—	Nil	0.005
Refractive Index			1.35-1.38	—	—	—
Coefficient of friction:						
P.T.F.E. to P.T.F.E. (ideal)			0.04	—	—	—
P.T.F.E. to Polished Steel (ideal)			—	—	—	0.04
P.T.F.E. to Polished Metal			0.09-0.12	—	—	—
P.T.F.E. to P.T.F.E.			—	—	0.1-0.121	—
P.T.F.E. to Mild Steel			—	—	0.2-0.3	—
Flammability		A.S.T.M. D635-44	—	—	Nil	Non-flam

NOTES: (a) $\frac{1}{8}$ in. sheet, short time. (b) for sample 0.005 in. thick. (c) $\frac{1}{32}$ in. sheet.

FURTHER PROCESSING OPERATIONS—In recent years, many conventional plastics-processing techniques have been adapted to p.t.f.e. despite its apparent intractability. Calendering (rolling) of coagulated dispersion polymer containing white oil as lubricant has been used to prepare tape from extruded rod; the oil is later extracted by means of a solvent.[13] Film produced in this way shows a number of advantages over material produced by the alternative methods of veneering, spraying or dipping (dispersion methods):

(i) It is freer from pinholes and other faults, thus allowing the use of thinner single sheets of the plastic for diaphragms, etc., without risk of permeation.

(ii) Being unsintered, the tape may be wrapped over a component (e.g., for electrical insulation purposes) and sintered *in situ*, the resultant shrinkage ensuring a tightly-wound layer.

(iii) It is possible to obtain a combination of high tensile strength with high breaking elongation:

	Longitudinal	*Transverse*
T.S. p.s.i.	6000-7000	3250-3500
E.B. per cent	200- 250	1000-1250

Another example of a rather similar nature is disclosed in a recent patent[14] which describes a chemically-inert hose having a lining of initially unsintered paste-extruded p.t.f.e. which is sintered and fused to a reinforcing layer of glass fabric after being laminated into pipe form.

DISPERSION TECHNIQUES—Although most p.t.f.e. fabrication utilises either granular or coagulated dispersion polymer, the fluid dispersions themselves are useful in a wide range of applications, e.g., fabric impregnants, film, surface coatings (particularly for wires) and porous metal impregnants. Space does not permit discussion of these dispersions but their applications have been reviewed fully elsewhere.[15]

BONDING—This is not yet feasible as present methods are difficult to apply. For example, one patent[16] requires the p.t.f.e. surface to be dipped into a 1 per cent solution of metallic sodium in anhydrous liquid ammonia. The use of a sodium naphthalene complex dissolved in tetrahydrofuran is a recent development which shows promise.[17] Pressure-sensitive adhesives have been suggested for assembly purposes; a p.t.f.e. tape coated with a polyvinyl ether has been used for the splicing of high voltage cables, advantage being taken of the plastics' very low water absorption in this application.[18] Welding of film and tape is feasible and this has even been suggested for thicker sections.[19]

Engineering Applications of P.T.F.E.

The applications of p.t.f.e. will be clear from a study of the properties of the material (Table 1). In this section, no attempt is made to document exhaustively all the uses of p.t.f.e. since this is readily available in the literature of the leading fabricators but, rather, attention is drawn to some of the more recent developments which seem to show promise.

LOW-FRICTION AND NON-STICK APPLICATIONS—We may recall that Dr. Fuchs' 'Otter' aircraft at Scott Base was fitted with skis faced with p.t.f.e. to enable it to slide over ice at very low temperatures with very little friction. Other aircraft applications include self-lubricating bearings in landing gear[20] and in instruments where lubricated jewels do not give satisfactory low temperature service.[21] The low coefficient of friction to metals makes p.t.f.e. an interesting material for bearing surfaces, even at normal temperatures. The polymer itself shows poor cold-flow characteristics and will not support any but the lightest loads. This creep effect may be reduced by the incorporation of suitable fillers such as glass fibre and asbestos, as the figures[22] in Table 2 indicate.

Additional evidence is provided by Mitchell and Pratt[23] who showed that incorporation of 30 per cent bronze fibre into a p.t.f.e. bush improved wear rating a thousand-fold.

For heavier loads, porous metal bearings impregnated with p.t.f.e. dispersion have been developed by the Glacier Metal Co. The material consists of a steel backing on to which is sintered a very porous layer of spherical bronze powder (89 Cu 11 Sn) about 0.010-0.015 in. thick. This porous bronze is impregnated with p.t.f.e. dispersion and sintered leaving a residual surface film about 0.001 in. thick. Optimum p.t.f.e./bronze ratio should be greater than 32 per cent by volume of p.t.f.e. Tested in the form of thrust washers,[24] this showed less wear than other conventional dry bearing materials (see Table 3).

Despite these favourable laboratory tests, it appears that these bearings have been slow in gaining acceptance industrially except for service under extreme conditions as for example in the Rolls-Royce Avon R.A.29 turbo-jet engine.[25] It is possible that the variability in performance observed with these dry bearings is associated with the "bedding-in" period. During this, the free p.t.f.e. at the surface of the bronze matrix is rapidly worn away and coats the metal shaft. If during service, this film of p.t.f.e. breaks down allowing the metal of the shaft to contact the bronze, the frictional heat forces more p.t.f.e. out of the bronze "sponge" by virtue of its higher coefficient of expansion, so repairing the damaged film.

Improvements in bearing wear have been achieved by incorporating fillers. Molybdenum disulphide is of some assistance but best results have been obtained by inclusion of 30 per cent lead powder with the p.t.f.e. Mitchell[25] reports tests on such material (Glacier Metal Co. "DU") in comparison with a standard p.t.f.e. impregnated bronze ("DP"). Referring to Table 3, DU material showed less than 0.005 in. wear in over 1000 hours' service and PN (p.s.i. × rev./min.) v. time plots were of the form shown in Fig. 4.

Bearing performance was not affected by temperatures up to 240 deg. C. and was insensitive to the surface finish of the mating material and to initial clearances of up to 0.003 in. between bush and shaft. Loads and speeds allowing 1000 hours' continuous operation were given in terms of PN values as follows: (a) For thrust washers, PN = 7.8×10^4 p.s.i. rev./min. (b) For unidirectional load bushes, PN = 11.5×10^4 p.s.i. rev./min. (c) For rotating load bushes, PN = 20.0×10^4 p.s.i. rev./min.

Other applications include non-stick roller coverings, linings for hoppers, chutes and guides, barrier tapes for heat sealing equipment, and in non-lubricated piston rings.[27]

CHEMICAL RESISTANT APPLICATIONS—P.t.f.e. is probably the most inert material of construction available to the designer. Exotic applications include the storage of rocket fuels[28] in a seamless "expellent bag" 10 ft. in length and 3 ft. in diameter working in the temperature range −270 deg. C. to +290 deg. C. A recently announced displacement pump for acids and alkalis is made entirely from p.t.f.e., body, valve chests, valve discs, glands and springs.[29] Gaskets and seals have been designed for a variety of applications care being taken in the design to minimise creep effects.[30, 31]

ELECTRICAL APPLICATIONS—The electrical properties of p.t.f.e. are very similar to those of high-density polyethylene with the advantages of a greater working temperature range, better ageing and lower water absorption. Principal outlets are in valve, cathode ray tube and crystal holders, insulating tapes and sheets, as dielectric and insulant in high temperature cables, in wire enamelling, as spacers and connectors in high-frequency cables, as hermetic seals for condensers and transformers and as general insulants for motors, transformers and other high temperature equipment. Recent developments include the use of p.t.f.e./glass-cloth laminates in printed circuitry.[32]

P.t.f.e. is a useful engineering material for application under difficult conditions of corrosion or temperature or where its valuable mechanical and electrical properties can be properly exploited. It suffers from the disadvantages of high cost and difficulty of fabrication compared with other plastics materials. While cost is steadily dropping and improved fabrication methods are being devised, it is difficult to foresee startling developments along any one particular line. Rather, it would seem that p.t.f.e. will remain a special-purpose material, while the real expansion will take place in the range of applications found for it by the design engineer.

TABLE 2. Effect of fillers on creep resistance of p.t.f.e.

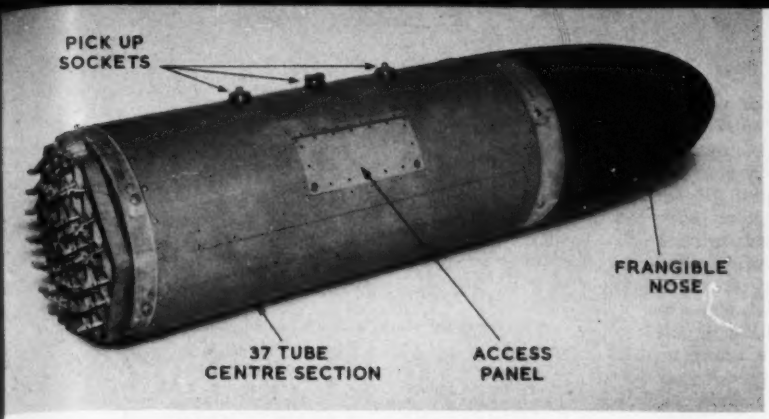
Load p.s.i.	Permanent Deformation per Cent	
	Unfilled p.t.f.e.	p.t.f.e. contg. 20 per cent chopped glass-fibre
2000	1.8	0.5
3000	12.3	2.5
4000	25.9	8.3

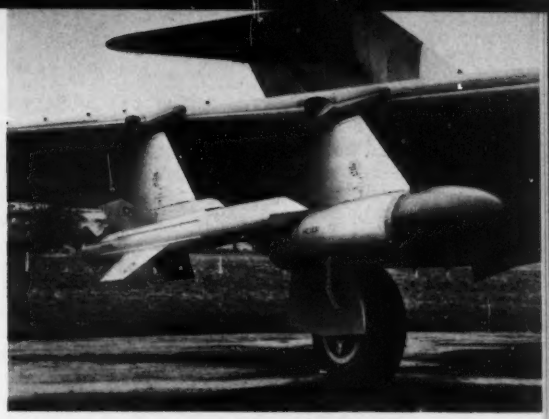
TABLE 3. Comparison of wear properties of p.t.f.e.-impregnated bronze with other bearing materials.

Material tested	Test time (hr.)	Wear (in. x 10^{-3})	Wear rate (in. x 10^{-4}/hr.)
P.t.f.e.-impregd. bronze	200	5.0	0.25
Phenolic resin + MoS_2	73	4.0	0.55
Graphite + lead bronze	158	12.7	0.77
Oil-impregd. bronze			
(a) hydrocarbon oil	105	10+	0.95
(b) fluorocarbon oil	42	11.1	2.6
(c) silicone oil	6.3	10+	16.0
Graphite, bearing type	24	9.6	4.0
Porous bronze + 25 per cent MoS_2	16.5	7.0	4.1
Asbestos + resin + MoS_2	0.8	4.3	54
Nylon	0.3	10+	330

REFERENCES

(1) J. Gadsby, *Plastics Institute Trans.* (1954), **22,** No. 47, 5.
(2) Fluon-P.t.f.e. I.C.I. Ltd. (1957).
(3) *P.t.f.e.—its properties and applications.* Dunlop Rubber Co. Ltd. (1956).
(4) *P.t.f.e. Engineering.* Crane Packing Ltd. (1958). See also R. C. Doban, C. A. Sperati and B. W. Sandt. *S.P.E. Journal* (1955), **11,** (9), 17.
(5) P. E. Thomas, J. F. Lontz, C. A. Sperati and J. L. MacPherson, *S.P.E. Journal* (1956), **12,** (6), 89.
(6) R. K. Kirby, *J. Res. Nat. Bur. Stands.* 1956, **57,** No. 2, Research Paper 2696.
(7) F. M. Chapman and L. T. Bunn, *S.P.E. Journal* (1957), **13,** No. 2, 37.
(8) Tube Turns Plastics Inc. (U.S.A.) B.P. 782,700
(9) W. B. Thompson and R. E. Stabler. *Mod. Plastics* (1956), **33,** No. 6, p. 115.
(10) E. M. Elliott, *Plastics* (1958). **23,** No. 244, 8.
(11) I.C.I. Ltd., Plastics Division. I.S. Note No. 438, June 13, 1956.
(12) R. S. Mallouk and W. B. Thompson. Paper given at the S.P.E. meeting in Detroit, Jan. 1958. Abstracts: *S.P.E. Journal* (1957), **13,** No. 12, 65; *Mod. Plastics* (1958), **35,** No. 5, 230.
(13) Anon. *Plastics* (1958), **23,** No. 244, 31.
(14) Resistoflex Corporation (U.S.A.). B.P. 783,240.
(15) H. M. Whitcut, Paper given at the British Plastics Convention (1955). See also G. Bartczak, *Materials and Methods* (1955), **42,** No. 5, 93; *Modern Plastics* (1956), **34,** No. 1, 127.
(16) E. I. Du Pont de Nemours and Co. Inc. (U.S.A.). B.P. 793,731.
(17) E. R. Nelson, T. J. Kilduff and A. A. Benderly, *Ind. Engng. Chem.* (1958), **50,** 329. See also General Motors Corpn. (U.S.A.). U.S.P. 2,809,130.
(18) Anon. *Applied Plastics* (1958), **1,** No. 1, 37.
(19) Anon. *Plastics* (1957), **22,** No. 4, 113.
(20) Micromatic Hone Corpn., Micro-Precision Divn., *Rubber and Plastics Age* (1958), **39,** 216.
(21) H. S. White. *J. Res. Nat. Bur. Stands.* (1956), **57,** 185.
(22) J Gadsby. Answer given during discussion of his paper, Ref. (1).
(23) D. C. Mitchell and G. Pratt, *Scientific Lubrication,* Conf. Issue, December 1957, 156.
(24) D. C. Mitchell, *Scientific Lubrication,* Conf. Issue, December 1957, p. 67.
(25) I.C.I. Ltd. *New Scientist,* July 31 1958, p. 509.
(26) D. C. Mitchell. *The Engineer* (1958), **205,** No. 5335, 625.
(27) R. D. Taber and F. A. Robbins, *Mech. Engng.* (1957), **79,** 838.
(28) N. H. Langton and S. N. Angrove, *Appl. Plastics* (1958), **1,** No. 6, 21.
(29) Anon. *Appl. Plastics* (1958), **1,** No. 4, 40
(30) H. R. Stephens, *Plastics Tech.* (1957), **3,** 113; P. Andreutsch and O. L. Anderson, *Rev. Sci. Instrum* (1957), **28,** 288.
(31) For example, Connecticut Hard Rubber Co. B.P. 785,479 (Hermetic seal); General Motors Corpn. B.P. 784,770 (Motor car door seal).
(32) L. B. Allen, D. E. McElroy and S. J. Stein, *Electrical Mfg.* (1957), **60,** 124; D. E. McElroy and S. J. Stein, *ibid* (1957), **60,** 126.





The Microcell glass fibre rocket launcher is designed to fire 37 projectiles. *Right* is seen the rocket pack fitted under the wing of the Gloster Javelin Mk. 7 in the first picture to be released showing the launcher attached to an aircraft.

GLASS FIBRE FOR ROCKETS AND LAUNCHERS

THE high strength to weight ratio of glass fibre reinforced plastics has led to their development for rocket powered missiles and launchers as well as for research vehicles which are used for investigation into the upper atmosphere during the international geophysical year.

It is interesting that the use of reinforced plastics for these purposes shows many advantages over metals. For instance, when used for military equipment the materials are readily available in the U.K.; they are non-strategic and are not reclaimable by an enemy in time of war. A further advantage is that they can be stored for long periods under extreme climatic conditions without deterioration and this reduces the amount of service maintenance. The clean aerodynamic finish of the glass fibre plastics, when produced with correct tooling, eliminates special finishing operations and the low density of the material enables a more robust design to be produced for a given weight, thus avoiding the use of very thin sections which are sensitive to handling. The low thermal conductivity and high specific heat of plastics compared to metals ensures that heat dissipation from exhaust gases is insufficient to burn away a significant amount of wall material and also gives an appreciable time delay before heat affects the fuel and sensitive instruments. The comparatively low value of Young's modulus is sometimes an advantage to avoid high thermal stresses being set up.

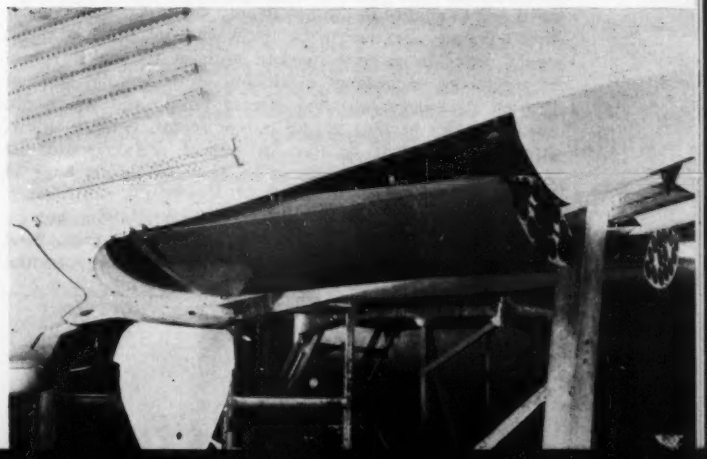
The research and development programme of Bristol Aircraft Ltd. in the rocket motor tube field has proved the practicability of producing rocket motor tubes of resin-impregnated glass fibre. Many types of rocket motor cases are being manufactured, ranging in length from 24 in. to 18 ft. and in diameter from 6 to 18 in. A rocket motor case is basically a lightweight pressure vessel capable of containing a propellant charge which, during burning, generates high-pressure gas at high temperature. Because of the critical relationship between weight and performance, the rocket motor case must be as light as possible consonant with adequate strength. In the past, production has been based on the use of low alloy steels, but the machining, welding and heat treatment must be controlled to very fine limits and these have required very considerable skill in manufacturing. In these respects the use of glass fibre plastics has shown some advantages.

These developments have naturally led to the manufacture of high pressure vessels for gas storage in guided missiles using glass fibre plastics. They vary in shape from the spherical to the cylindrical and annular, and may be used to store oxygen, air or nitrogen to provide ancillary services. Pressure vessels in current production have capacities ranging from 1½ to 32 litres and are designed for working pressures up to 6,000 p.s.i. In addition, in some instances, resin-impregnated glass fibre shows some advantages over steel as a structural material for pressure vessel fabrication and this method of manufacturing is being developed for the manufacture of rubber-lined pressure vessels.

Another interesting development is the production of glass fibre rocket launchers by Microcell Ltd. A launcher, which is capable of firing 2-in. fin stabilised rockets, consists of a multi-tube centre section moulded as a glass fibre polyester resin matrix. The launchers may be mounted in the aircraft fuselage and made retractable or they may be pylon-mounted under the aircraft wing. The retractable form has a front blast plate of the same material attached to the forward face to withstand all the rocket blast. The pylon mounted form is fitted with a frangible nose piece which breaks into small particles at the first salvo and the rear end of the centre section is finished off with a glass fibre polyester resin tailcone designed to give low aerodynamic drag and to carry away rocket exhaust gas.

These launchers have been designed for air-to-air and air-to-ground rocket armament for high performance aircraft such as the Royal Navy's Sea Vixen and Scimitar and the R.A.F.'s P.1.

An example of a glass fibre retractable rocket launcher (for 14 projectiles) fitted to the de Havilland Sea Vixen.



HOW DESIGN CAN AFFECT THE FATIGUE OF WELDED STRUCTURES

Fatigue is responsible for a large proportion of engineering failures; the way in which the design of welded joints can affect fatigue failure is discussed here

by T. R. GURNEY, M.A., A.M.I.C.E.*

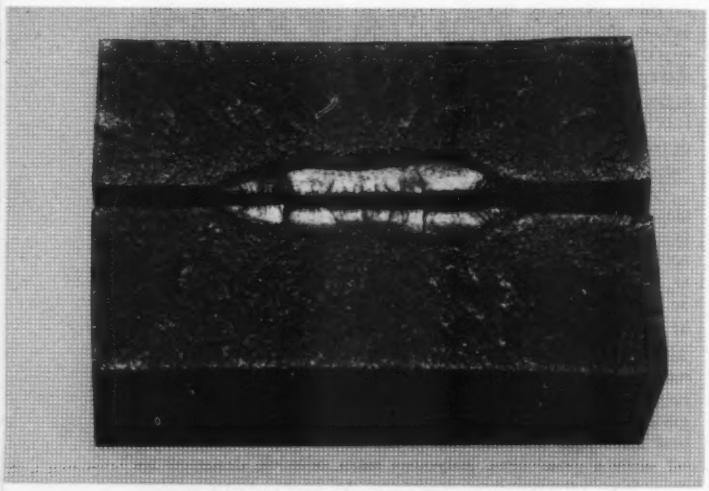


Fig. 1. Fracture surface showing fatigue crack which has propagated as a brittle fracture.

IN these days of great scientific activity it is not at all unusual for an entirely new technique to become, in a comparatively short period of time, an accepted part of the industrial scene. Today, welding cannot be regarded as entirely new but, as an industrial process, it has advanced with great rapidity in the last twenty years. The reasons for this advance are numerous. However, its present status could never have been reached without the development of electrodes capable of producing joints in mild steel of greater static strength than riveted joints, and which are even superior to that of the parent metal. Unfortunately, strength equivalent to that of parent metal cannot be easily obtained when repeated loading conditions have to be catered for.

REPEATED LOADING—If failure is brought about not by static loading, i.e., by one loading cycle in which the load increases gradually from zero to a maximum, but by the repeated application of loading cycles, the strength of most practical forms of joint, whether riveted or welded, is found to be considerably less than that of the parent metal, even for mild steel. Thus fatigue failure may be defined as failure under repeated applications of load of insufficient magnitude to cause static failure. This type of failure is of course equally possible in solid metal containing no joints.

Fatigue cracks are usually very difficult to see, particularly in their early stages. This is because the cracks are extremely fine and the surrounding material shows no sign of deformation. Herein lies the particular danger of fatigue; that the crack may propagate to catastrophic dimensions before it has been discovered. Fatigue cracks can be recognised very easily after the crack has been opened up, when the origin of the crack will be found to be surrounded by a smooth, silky area, often marked by a series of faint concentric rings. This appearance is quite different to that of a brittle fracture although, superficially, the two types can look very similar. The brittle fracture usually has a wholly crystalline appearance, and this difference between it and a fatigue crack is illustrated in Fig. 1, which shows a fatigue crack which has propagated as a brittle fracture.

BASIC FACTS ABOUT FATIGUE—Before going on to consider when fatigue is of importance and what steps can be taken to prevent failure, it is necessary to appreciate some of the basic factors affecting this type of failure. The most important of these is that failure will only occur as the result of a large number of loading cycles and these may not occur before the passage of several years. By that time the structure will often have passed beyond the knowledge of the designer and this, coupled with the natural desire of firms not to publicise their failures, is probably the reason for the view often expressed by designers that "fatigue failures never happen". Unfortunately, this is a completely erroneous impression and, in fact, fatigue failures are quite common.

For any structural detail subjected to fatigue loading conditions there exists a relationship between the applied stress and the number of cycles of loading required to cause failure. A typical curve for a detail in mild steel subjected to stresses varying from zero to some maximum tension is shown schematically in Fig. 2, from which it will

* *Senior research officer, British Welding Research Association.*

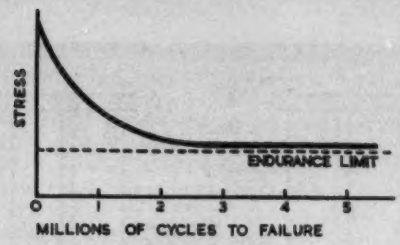


Fig. 2. Schematic S-N diagram for mild steel.

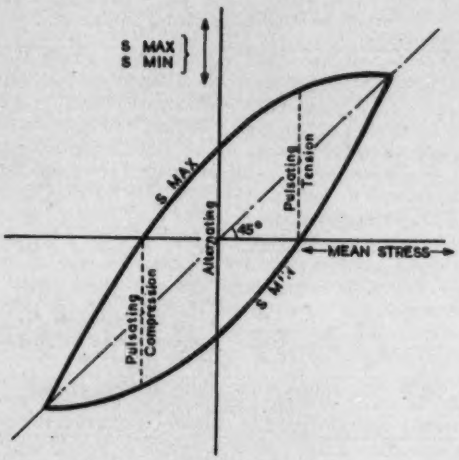


Fig. 3. Schematic Smith diagram.

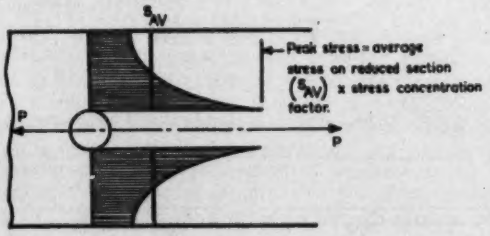


Fig. 4. Stress distribution in a tension member containing a circular hole, showing the stress concentration effect.

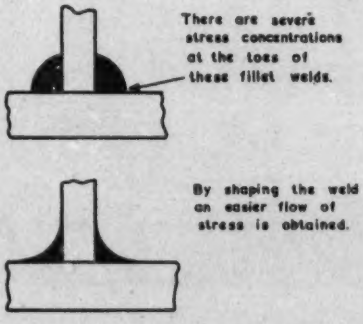

There are severe stress concentrations at the toes of these fillet welds.
By shaping the weld an easier flow of stress is obtained.

Fig. 5. Fillet-welded joints. A more uniform flow of stress can be achieved by shaping some welds, but close control is needed.

be seen that after about two million cycles there is no appreciable drop in strength. The exact number of cycles depends on the detail involved and may be as much as ten million. For aluminium alloys, however, the curve is usually somewhat different in that most of these alloys show no endurance limit, so that strength continues to fall for increasing life.

Since the stress variation in many structural members does not vary from zero to some maximum tension—for example the main girders of a bridge always carry a stress due to dead load and this will have superimposed on it a stress due to repeated applications of live load—it is necessary to consider the effect of other load cycles. Thus, for any detail it would be possible to plot the relationship between the limits of the applied stress range and the corresponding mean stress, which combined would cause failure after a certain number, say two million, load cycles. This is termed a Smith diagram and is shown schematically in Fig. 3. It will be seen that the greatest stress range, represented on the graph by the vertical distance between the two curves, occurs when the mean stress is zero and the stresses are alternating between equal tension and compression. As the mean stress is either increased or decreased, the safe stress range decreases although the absolute value of maximum stress is increased.

STRESS CONCENTRATIONS—Unfortunately for the designer, it is not possible just to determine in the laboratory the complete Smith diagram for the material in which he is interested and to use the relevant information, scaled down by a suitable safety factor, for design purposes, since the fatigue strength of a structure is not related to the strength of the material from which it is built. Fatigue strength is not a mechanical property of the material in the same way as hardness or ultimate tensile stress, and tests carried out on the parent material will yield results depending very much on the shape and size of the test piece, the surface condition and the method of testing. In particular, completely different results will be obtained if tests are carried out on specimens containing notches of any sort.

Effect of Notches

This notch effect is perhaps the most important factor of all in determining the fatigue strength of a structure. In this context "notch" may be interpreted as any geometrical or metallurgical discontinuity. The action of a notch is to produce a stress concentration. For example a single circular hole, such as a bolt hole, in a tension member may increase the stress locally to three times the value of the average stress, as shown in Fig. 4, while a hole in the web of a girder may locally quadruple the shear stress. Under static loading conditions such stress concentrations are nearly always ignored, but these local high stresses can, under repeated loading, initiate fatigue cracks. Having been initiated, the crack itself acts as a stress concentration which aids crack propagation. Hence it will be seen that under fatigue loading conditions stress concentrations are inevitably potential sources of failure. And since the most severe discontinuity in a structure usually occurs at one of the joints—all joints of course are points of stress concentration—the fatigue strength of a structure depends largely on the detailed design of the joints.

WELDED JOINTS—It so happens that the versatility of welding leads to the possibility of the introduction of discontinuities which can be much more variable than is normally obtained with riveting or casting, so that the careful design of welded structures is particularly important. For static loading, welded joints can be made so that they

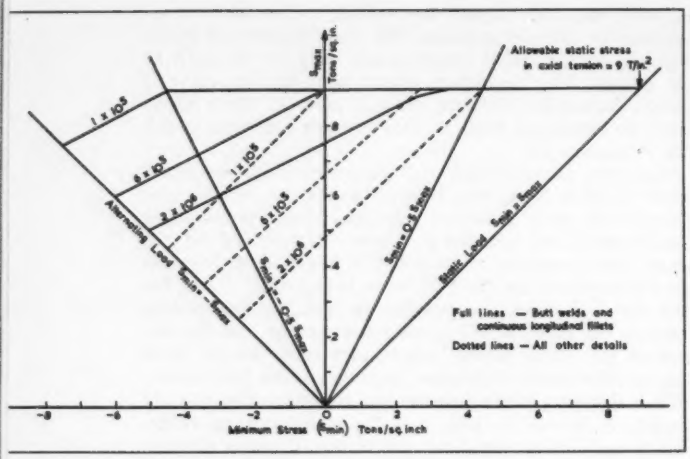

Allowable static stress in axial tension = 9 T/in.²
Stress Tons/sq. in.
Alternating Loads
Static Load
Full lines — Butt welds and continuous longitudinal fillets
Dotted lines — All other details
Minimum Stress (σmin) Tons/sq.inch

Fig. 6. Graph showing permissible design stresses in mild stress tension members subject to fatigue loading. (B.S. 153.)

are stronger than the members joined by suitable adjustment of the weld size. But such a method of design to resist fatigue loading conditions is impossible, since the fatigue strength depends on the average stress in the member and the stress concentration factor at the joint. Consequently, it is the size of member, and not usually of the joining weld, that has to be adjusted and this cannot be done, in many cases, until the exact detail of the joint is known.

A butt weld provides reasonable continuity for the flow of stress, but the weld reinforcement still produces a stress concentration and a good quality transverse butt weld will always fail from the edge of the reinforcement. Research is going on at the moment to try to discover what are the important factors about the shape of reinforcement and their relation to fatigue strength, but it has definitely been proved that if the weld reinforcement and sealing run of a good quality weld are machined flush with the surface the fatigue strength is raised to that of the parent metal, because of the elimination of the stress concentrations. Plain mild steel plate in the as-rolled condition has a fatigue strength at 2×10^6 cycles, of approximately 16 tons/sq. inch when pulsating in tension between zero and a maximum, but for a normal good quality manual butt weld this is reduced to approximately 10-11 tons/sq.inch. Much lower strengths are found, however, if the weld is of poor quality. In particular, lack of penetration at the root may produce a very serious reduction in strength.

Shaping Fillet Welds

On the other hand, the geometry of a fillet-welded joint is such as to produce greater stress concentrations, and therefore lower fatigue strength. In general, increasing the size of a fillet weld does not improve the fatigue strength of a joint because the stress concentration is not reduced. In fact the weld need only be large enough to carry the load statically, the fatigue strength depending on the nominal stress in the parent material. A worthwhile increase in fatigue strength can be obtained by suitable shaping of the fillet weld to produce a more even flow of the stress field as shown in Fig. 5. Very close control of the welding is, however, necessary to achieve the required form consistently.

DESIGN OF STRUCTURES—The possibility of fatigue failure should be considered when designing any form of

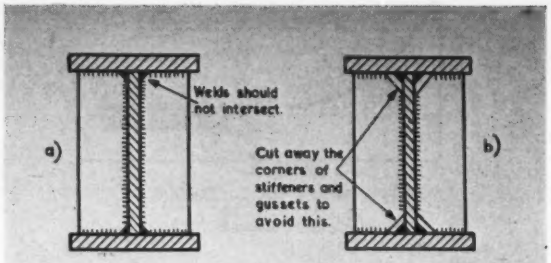


Fig. 7. The intersection of welds should be avoided. This can usually be achieved by cutting off corners.

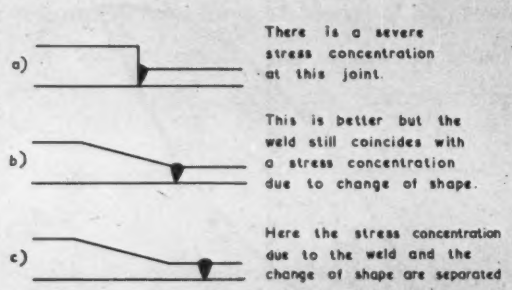

a)
There is a severe stress concentration at this joint.
b)
This is better but the weld still coincides with a stress concentration due to change of shape.
c)
Here the stress concentration due to the weld and the change of shape are separated

Fig. 8. Transitions in thickness should be carried out gradually.

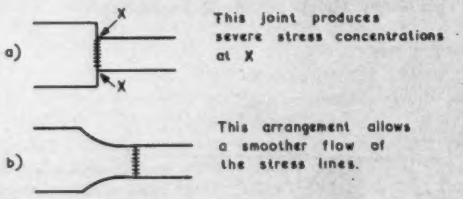


Fig. 9. Sudden changes of section should be avoided.

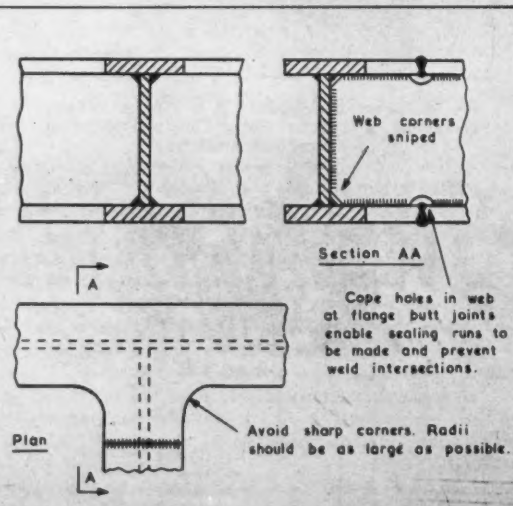

Web corners sniped
Section AA
A
Cope holes in web at flange butt joints enable sealing runs to be made and prevent weld intersections.
Avoid sharp corners. Radii should be as large as possible.
Plan
A

Fig. 10. Joint between girders. Note the avoidance of sharp corners and intersecting welds.

structure liable to suffer repeated loads. It can safely be said that there is no possibility of failure in buildings unless they contain such machines as travelling cranes; but failures in gantry girders are not unusual and failures in the supporting steelwork, probably due to lateral surge, have been recorded. Fatigue cracks are comparatively rare in highway bridges, where the stresses due to live load are usually only a small fraction of those due to dead load, but railway bridges are much more prone to failure. However, turning from the field of civil engineering to that of the structural-mechanical engineer, it would be impossible to list all the structures which may be affected, although the list would certainly have to include such items as earth-moving machinery, cranes, locomotive and vehicle frames, press frames, diesel engine frames and the like, in all of which failures have certainly been recorded. The field of aeronautical engineering is outside the scope of this article, but the same basic principles apply.

The only official guidance available to designers in this country on permissible design stresses for mild steel structures subject to fatigue loading is that contained in the draft revision of B.S. 153* for the use of structural steel in bridges, and details of these recommendations are summarised in Fig. 6. It will be seen that one set of curves covers the use of butt welds and continuous longitudinal fillet welds, while the other set refers to all other details. It will also be seen that, in order to be able to select the correct design stress, the designer must first decide how many load cycles the structure is likely to suffer during its expected life, since the allowable stresses are progressively reduced for each of the three specified 'lives' of 100,000, 600,000 and 2,000,000 cycles. Although fatigue failure may of course, occur after fewer than 100,000 load cycles it is reasonable to assume that it is unlikely to do so if the normal allowable static stresses are adhered to in the design and if no grossly bad details are introduced into it. In this respect it should be appreciated that all the allowable stresses quoted in this standard are inevitably based on a simplification of the problem which assumes good design and workmanship.

Since it appears from a study of several service failures and of current design practice that some of the basic principles of the design of structures subject to fatigue loading are not fully understood, it is hoped that the following brief survey of some common faults, all of which have led to failures, may be of general use. As has already been intimated, the most important requirement for designers of fatigue loaded structures is for them to appreciate the importance of eliminating stress concentrations, and all the examples which follow are in some way related to this dictum.

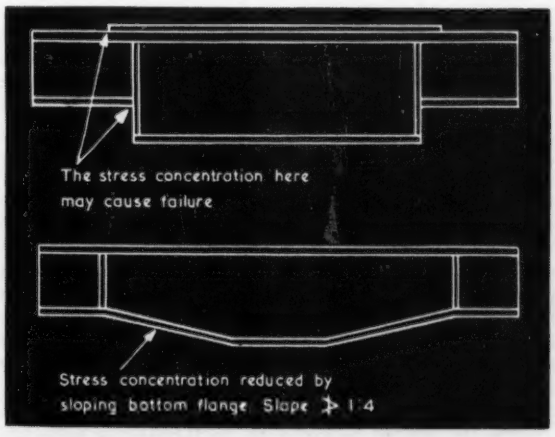


Fig. 11. Strengthening beams. Corner plates and other sharp changes of section should be avoided.

DESIGN OF DETAILS—One of the most common faults is to design structures with intersecting welds. Since every weld produces a stress concentration the point of intersection suffers a stress concentration effect from each weld, and this is usually accentuated by a flaw in the weld at the point of intersection, since it is difficult for the welder to start or finish welds neatly at a corner. A typical example of this fault often occurs where a stiffener or gusset is attached. Fig. 7(a) shows a case where the web-to-flange welds of a fabricated beam are intersected by the welds connecting the stiffener to the beam. This can be avoided by the simple expedient, illustrated in Fig. 7(b), of cutting off the corner of the stiffener. A reasonably liberal amount should be cut out so as to ensure that the welder does not try to fill up the gap with weld metal.

Welding Different Thicknesses

Another common fault is to weld two plates of different thicknesses to each other directly. It is quite obvious from a study of Fig. 8(a) that this must produce a severe notch effect. Ideally the thicker plate should be tapered to the thickness of the thinner one and the weld placed some distance away from the transition point, as shown in Fig. 8(c) but, if this is impossible, placing the weld at the transition point, as in Fig. 8(b), is better than the original sharp change of section.

A similar case occurs when it is desired to join two plates of different widths in plan view shown in Fig. 9(a). A curved transition as shown at (b) in Fig. 9 is the correct solution to this problem and it should be noted that the radii of the curves should be as large as possible. An almost identical problem occurs when it is necessary to connect the flanges of two girders at right angles to each other, as might happen in a bridge or in the underframe of a locomotive. The correct detail for this type of joint is illustrated in Fig. 10, where the measures taken to ensure that there are no weld intersections should also be noted. It will of course be realised that it is impossible to make this sort of joint when rolled-steel members are used, and consequently their use in such connections should be avoided.

Some of the methods commonly used for strengthening beams, although suitable for static loading conditions, have proved to be very unreliable under repeated loading. One of these is the use of partial length cover plates, which introduce severe stress concentrations at their ends. If local strengthening is required it is far better locally to increase the flange width, tapering it to the width of the least wide section. Similarly, a sudden change in depth of a beam can lead to failure and it is better to change the depth gradually as indicated in Fig. 11.

Although this list is by no means comprehensive it does include most of the common major errors. It will be noted that the accent has been on detailing rather than stressing. Although fatigue failures could be avoided by the use of very low stresses in design this is not entirely necessary, and the extra cost that would be involved in so doing can be set against the extra cost involved in using some of the better details. In this respect it should be noted that, since the fatigue strength of a structure depends on the fatigue strength of the joints, all the scantlings would have to be determined using the low stresses, so that in fact the use of better details may well show a saving when the costs are computed over the structure as a whole.

* It should be noted that the revised BS. 153 is at present a recommendation, and the use of the information it contains should be based on this understanding.

NEW IDEAS IN DESIGN

Outstanding products in current manufacture

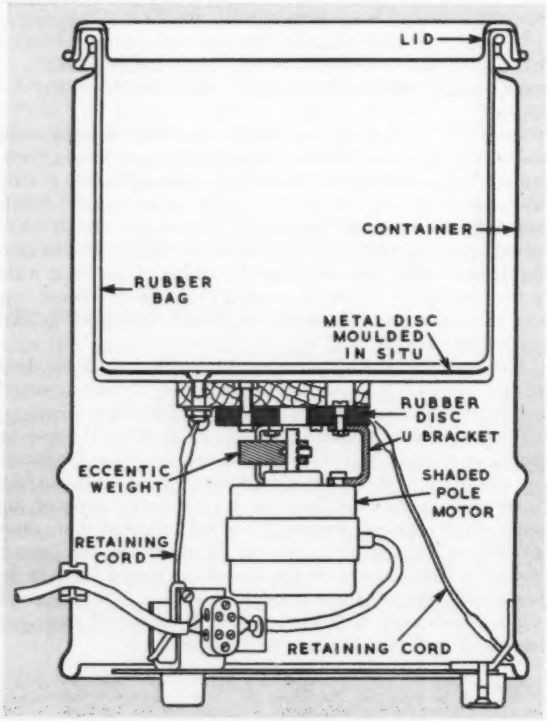
Impeller Eliminated in New Washing Machine

VIBRATION of a moulded rubber bag provides the necessary water turbulence in the Foamatic, a washing machine for the small household by Rolls Razor Ltd.

The walls of the bag are caused to vibrate by the out of balance forces set up by the rotation of an eccentric weight attached to the shaft of a small electric motor. The motor, which is of the shaded pole type, is attached to the base of the bag by three U-shaped brackets. Between these and the bag are a rubber disc and a local stiffening block. To provide the necessary rigidity in the base of the bag and means for attaching the motor, a metal disc, moulded in situ in the base of the bag carries the attachment studs. To prevent distortion of the bag by the weight of the motor when the machine is inverted, as might occur in transport, three retaining cords attach the base of the bag to the cylindrical outer container. A lid is provided to prevent splashing of the suds. Emptying is carried out by a simple siphonic pump operated by the cold water tap.

Only three gallons of hot water are required to fill the tub and four pounds (dry weight) of laundry can be washed. Topping up with hot water is only necessary from time to time during the washing operation as the heat losses are small owing to the good heat insulating qualities of the rubber tub.

Other advantages claimed include a gentle washing action, which does not damage delicate fabrics and woollen goods, small size and portability (empty weight 26 lb.) low purchase price and operating cost. The shaded pole motor consumes only 80 watts.



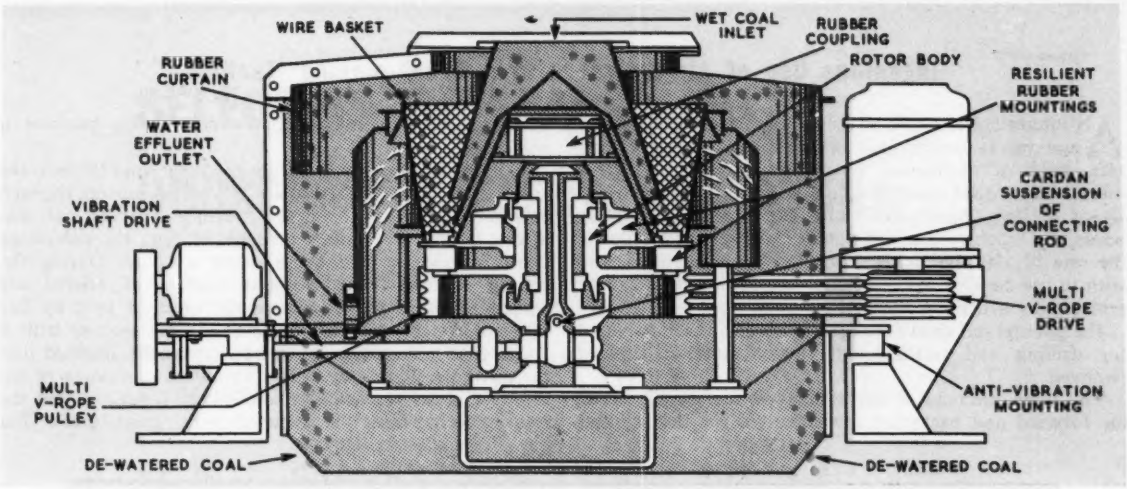
Detachable Hydraulic Wheel Assemblies

FOR loading large crates and containers into and out of the modern type of freighter aircraft, Electro-Hydraulics Limited have developed a combined jack, oleo pneumatic shock absorber and wheel assembly. By means of quick release fasteners these can be attached to crates and containers. A built in lever enables the container to be jacked up to give 6 in. ground clearance and then wheeled where required. The units are normally non-castoring, but the removal of a locking pin provides full castoring.

In order to provide convenient points of attachment for the quick-release fasteners, e.g., where direct attachment to a crate is not possible, some form of framework must be provided which would depend on the nature of the product to be wheeled. In the case of a rectangular crate, a loading pallet with two upright members to carry the roll units would be used. This would be left in the aircraft. Using suitable attachment frameworks, many unwieldy items, such as boats and agricultural machinery, could be jacked up and towed by tractor.

These wheel assemblies would also appear to have possibilities for use in conjunction with large stillages, ore containers, etc., and also for moving heavy pieces of machinery within the factory and over uneven ground.

Coal De-watered by Spinning and Vibration

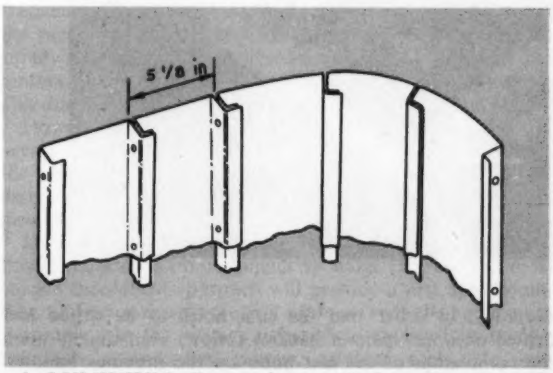


IN the Birtley-Humboldt centrifuge a slightly conical wedge wire basket, attached to a multi V-rope pulley by resilient rubber mountings, is caused to rotate and at the same time vibrate in a vertical direction by two electric motor drives. The working principle of this de-watering operation is shown in the section through the machine illustrated above.

Wet coal is admitted into the basket over a vertical distribution cone. The combined rotary and vibratory movement of the basket causes it to spread out over and climb up the wire mesh walls of the basket. On reaching the lip of the basket, the de-watered coal is thrown outwards against a rubber curtain and then falls downwards, the water passing outwards through the wire mesh. The rotor body, to which the wire basket is attached by the resilient rubber mountings, runs on tapered roller bearings on the vertical rotor shaft on the inside of which the crank drive for vibration motion is arranged. No axial vibration is communicated to the driving belts. Cardan suspension of the connecting rod permits the possibility of pendulum motion of the screen basket.

The drives to the screen basket being separate, considerable regulation of the machine is possible and fine coal, middlings, potash salts and industrial minerals can be de-watered. It is claimed that surface moisture of the centrifuged product is five to seven per cent and yield in solids 97-98 per cent. With coal, a throughput of 120 tons/hr. is possible.

A New Technique for Caravan Construction



ALUMINIUM alloy sections made from 22 s.w.g. strip (Noral M57S½H) form the basis of a new system of caravan construction which largely eliminates the traditional framework and provides a rivet-free exterior. The inventor, Mr. J. C. Boylan, of West Monkseaton, claims that any size or shape of van can be constructed by this method. The skin distortion caused by temperature changes is eliminated and an elegant rivet-free exterior is made possible. The shallow channel sections, having one re-entrant and one out-turned flange, are used to make the external walls, each section being riveted to the next. It will be seen from the illustration that a series of flanges on the inside are thus provided to which the lining can be fastened by self-tapping screws. The radiused corners are made by bending vertical sections together. An advantage is that prefabrication of the sections is possible.

In a prototype van produced by this method, sandwich construction was used for the floor and fibreglass for the roof. Horizontal formers were employed to reinforce the windows. For all the walls (including those of a built-in wardrobe and sink unit) of the 12 ft. van no more than 110 lb. of alloy were used.

Ingenious Use of Air Cylinders in a Brush-making Machine

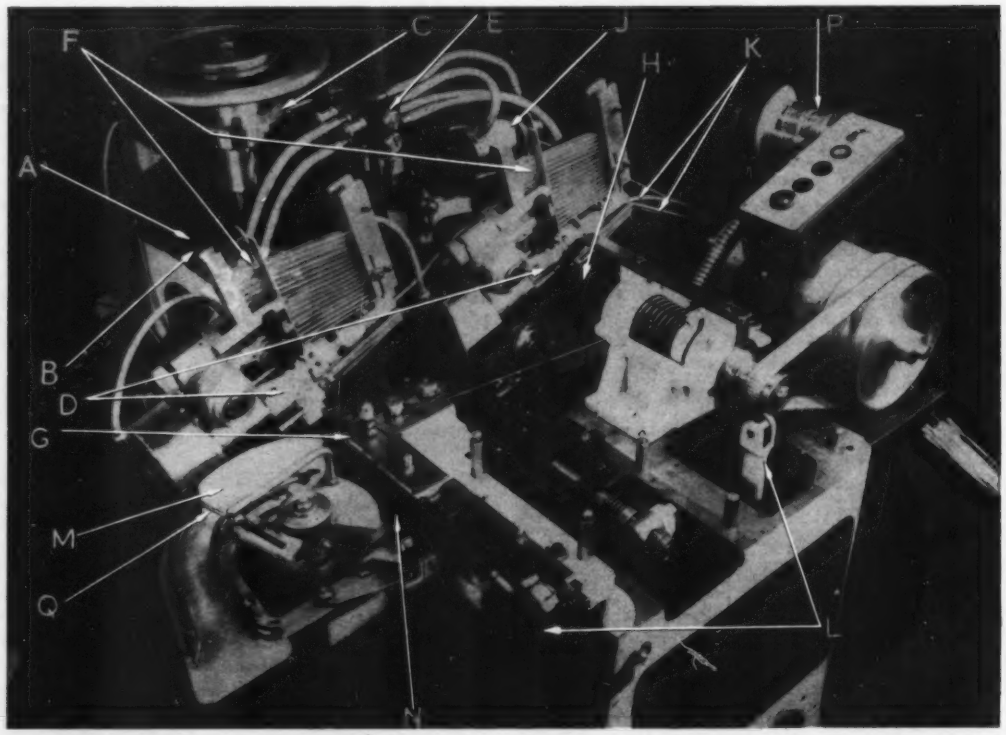
AN interesting example of the way in which air cylinders and valves can be used in a machine having a complex series of mechanical movements, is provided by a recently developed machine for filling tooth brushes by J. Evans & Son (Portsmouth) Ltd. Fitted with two filling heads, the machine can tuft handles with pre-cast holes at the rate of 1200 per hour. For those manufacturers who wish to use handles without holes, one tufting head can be replaced by a drilling head.

The photograph shows the upper part of a machine, fitted for drilling and tufting, with the sheet metal guard removed.

The main mechanical movements of the machine, i.e., the forward and backward movement of the drilling and tufting heads (G and H), and the sideways and vertical movements of the two rotary work holding heads (D), are brought about by a motor-driven flywheel operating a massive linkage system of which the only parts visible in the photograph are the two slide operating links (L). Air cylinders are used for clamping the brush handles and for rotating and locking the eight station rotary heads. The cycle of operations is controlled by a series of co-axially mounted cams positioned vertically at the rear of the machine. The upper of the two small cams (C) operates an air valve (E) which controls the air cylinder (J). This cylinder controls the unclamping of the brush handles in the rotary heads by Bowden cables (K). The lower of the two smaller cams controls the indexing of the rotary heads. A notched disc (B) to which the large slide operating cams (A) are screwed, controls the indexing of the brush hole spacings. The sequence of operations of this machine is as follows:

Unfilled handles are fed from the magazines (F) into the top stations of the rotary heads (D). After moving through two major indexings of 45 deg., tufting is carried out, and after a further movement through 90 deg., the completed brush is released and drops down a chute. During the tufting operation, the required number of bristles are picked up from the bristle supply which is held by bar (Q) and weight operated cable (N), and together with a staple cut from wire supplied by a spool (P), inserted into the tuft hole. The forward and backward movement of the tufting and drilling heads is continuous. It follows that the rotary heads must be indexed with great speed and accuracy, in order that the first holes to be tufted and drilled on a new pair of handles follows immediately upon the completion of the last holes on the previous handles. This indexing is performed by an air-operated rack and pinion mechanism. In the body of the machine (not visible in the photograph), an air cylinder moves the operating valve for the rack-operating cylinder rapidly towards a fast revolving cam for the brief period of time necessary for the lobe of the cam to operate the valve plunger, whereupon the valve is at once retracted.

The use of air cylinders has eliminated a series of links and levers, together with their associated wear problems, giving crisp operation of the clamping and indexing movements, while the retention of mechanical linkages for the main movements has ensured smooth operation with small power consumption.



SELECTION OF FRACTIONAL HORSEPOWER ELECTRIC MOTORS

In the first section of this article, published in our last issue, a broad survey was made of the common types of motor, with special reference to induction motors. The actual selection of motors is discussed here

by H. J. CADOUX, M.A. (Oxon), A.M.I.E.E.*

BEFORE typical applications of f.h.p. motors are dealt with, it is important that some of the more straightforward features to be decided are considered. Such simple requirements as the voltage of supply have, on occasion, caused serious difficulty. The main information required by a motor manufacturer before he can submit a motor is, therefore, briefly reviewed. A similar list of such informations is quoted in B.S.170.

SUPPLY—As much information as possible about voltage and frequency is desirable in addition to the basic declared values.

Values of torque, temperature-rise, etc., are usually quoted at the mean of the declared voltage range—and induction motor torques vary as the square of the supply voltage. A drop in voltage of 10 per cent therefore will result in roughly a 20 per cent fall in, say, starting torque. Changes of input due to small variations in voltage or frequency are not, however, usually of significance unless the motor is very tightly rated. Changes in speed due to supply variations are generally negligible for induction motors (except fan applications) but are likely to be noticeable for d.c. motors and in particular universal machines.

However, it is reassuring to know that the generally accepted performance figures for f.h.p. motors assume that the voltage may fall severely in service and they have been assigned the values they possess through long experience in meeting such contingencies.

LOAD, SPEED AND SIZE—A statement of horsepower required is often difficult to make. However, in most cases a theoretical approach will provide a first approximation, and prior experience will often serve if the application is complex. In the writer's experience, applications involving fans, compressors, pumps, machine tools, etc., are usually best tackled by theoretical means in the first instance, but apparatus involving complex mechanical movements and irregular pulsating loads must generally be determined by a trial test.

A decision on speed is usually easy. It should be remembered however that where an application is to be marketed for both 50 c.p.s. and, say, 60 c.p.s., the 60 c.p.s. motor will have to be of a larger output by 20 per cent than the 50 c.p.s. motor unless steps have been taken to compensate for the extra speed by reducing the torque requirement.

Load and speed being decided, the only other factors affecting size are those relating to enclosure, ambient condition and time rating.

ROTATION—There has been in the past a certain amount of ambiguity when referring to the direction of rotation, but it is becoming increasingly common practice to describe it in terms of clockwise or anticlockwise motion looking at the shaft end.

A.c. induction motors, single phase and polyphase, with the exception of shaded-pole motors, are usually supplied so that the direction of rotation can be altered. In the case of single-phase motors, this usually is done by interchanging two of the three line connections. Universal motors and d.c. motors are usually supplied with a preferred rotation so as to give the best commutation, and it is inadvisable to attempt to run these machines by reversing connections other than in the correct direction. For d.c. motors which have to reverse in service, a special setting of the brushes is required.

ENCLOSURE AND AMBIENT CONDITIONS—A decision on the enclosure required can usually be made as soon as operating conditions are known. From previous remarks it will be realised that if the choice can be narrowed to a drip-proof enclosure it will generally be highly economical. B.S. 170 contains explicit instructions for dealing with ambient temperatures and pressures outside those generally met in European conditions:

(a) For ambient temperatures in excess of 40 deg. C. the permitted rise will be reduced below 50 deg. C. by the amount the ambient exceeds 40 deg. C.

(b) The permitted rise at the factory will be reduced by 1½ per cent for every 1000 ft. between 3300 and 10,000 ft. above sea level on site.

It is pertinent to make a brief remark on humidity and tropical conditions generally. Most motors as made will withstand quite severe tropical conditions and extra precautions can usually be taken in the form of lacquering, plating etc. if so desired. Certain tropical insects attack insulations, and, for this reason alone, TE or TEFC motors are sometimes specified.

DUTY CYCLE TIME RATING AND REVERSING—A great many applications involve a complex duty cycle. So far as is possible, complete details about duration and value of load must be given. A decision as to the effective motor rating is essentially a job for the motor designer as he can interpret this in the form of a heat loss equation.

It usually takes some hours for a motor to attain its

* *Manager of research and development laboratory, Ranco Ltd., and until recently chief electrical designer for a major f.h.p. motor manufacturer.*

final temperature, the actual time being dependent not only on the motor itself and its heat dissipation, but also the mounting, ambient conditions, etc. It is generally taken to be an approximation to an exponential rise. Let us assume however that temperature rise (at any time) is proportional to the watts loss. To a first order, a motor which can normally produce, say, ½ h.p. continuously rated, will be able to deliver roughly twice that amount one-hour rated. Below one hour the increased output rises—subject to the obvious natural limits—roughly in inverse proportion to the time rating.

Reversing duty—in so far as it affects choice of a rating—complicates everything. Information must be given as to whether the motor is allowed to come to a halt naturally, by external braking, or is to be plug-reversed. Clearly if a motor is already under full load conditions running at its maximum temperature rise, in theory no extra starts or reversals are allowable and, in fact, it is only because most machines run somewhat under their allowable rise that extra starts and reversals are permitted. As a very rough guide it may be said that if a motor can tolerate say N starts/min, it can also tolerate ¼ N plug-reversals. Most firms however will readily supply information on this subject for any particular rating, but it will be appreciated that as the inertia of all moving parts affects the answer, the query is not one for the motor designer alone.

OVERLOAD PROTECTION—Efficient in-built over-load protection can be supplied by most firms for single-phase induction motors. It is not normally required for permanent-split or shaded-pole motors, nor is it normally customary to provide such protection on any motors rated at, say, below ¼ h.p. Many types of motor starter incorporate a form of overload current protection.

QUIETNESS—F.h.p. motors as generally supplied in standard ranges, operate with a good degree of quietness, it being customary to balance mechanically all rotating parts and take great pains by choice of suitable slot-combinations, etc., to minimise electrical noise and prevent resonance. Certain firms provide extra-quiet ranges of motors for the specialist—but in the last resort much always depends on the mounting and rigidity of the customer's apparatus. Single-phase motors for best results should always be mounted resiliently, and noise on induction motors can often be further reduced by provision of a suitable run-capacitor.

BEARINGS—The majority of f.h.p. motors for industrial and domestic use are fitted with sleeve bearings. They are relatively quiet in service and are now often capable of running unreplenished for the lifetime of the motor when it is on intermittent service, and with small annual increments of oil if the duty is continuous. Many modern motors are so constructed that they can be tilted to any angle and still retain their reserve of oil.

As an alternative, but somewhat more costly, ball bearings are generally available. These bearings are somewhat noisier than sleeve bearings, but this is of no importance on applications such as machine tools, etc., where the surrounding noise level is high. One restriction of sleeve-bearing motors is that their amount of axial thrust is generally limited and a considerably greater load can be tolerated on a ball-bearing machine.

The above remarks apply more to the larger types of f.h.p. motor, say, from 1/10 h.p. upward. There is no sharp division, but for smaller motors than this, particularly of a slightly lower quality, sintered self-aligning bearings will frequently be found.

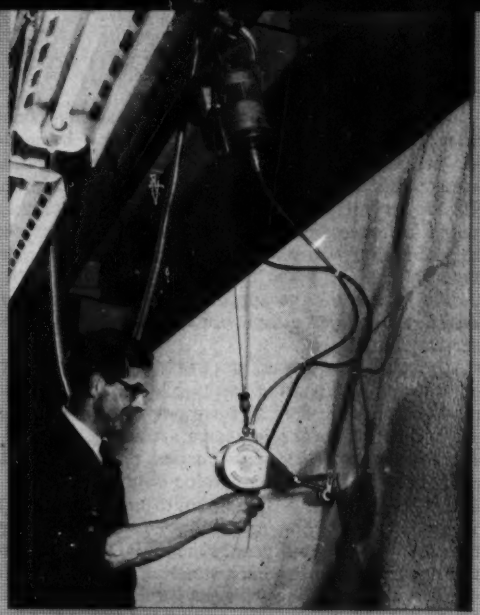
TYPE OF DRIVE—Some indication of type of drive will be required for a new application. Many applications,

TABLE I —Examples of applications for f.h.p. motors.

APPLICATION	STARTING TORQUE	NOISE REQUIREMENT	METHOD OF DRIVE	SPEED CONST. OR ADJUSTABLE	USUAL MOTOR ENCLOSURE	REVERSALS	POSSIBLE TYPES OF MOTOR		
							USUALLY	SOMETIMES	REMARKS
Industrial Applications									
Small Office Machinery	M/L	Usually quiet	Gear/Belt	Constant	Open	—	Split-phase	Perm.-split Universal	Universal not always suitable due to low noise requirements.
Air Compressor	H	—	Direct/Belt	Constant	Drip-proof	—	Cap.-start	—	—
Refrigerator	H	—	Belt	Constant	Drip-proof	—	Cap.-start	—	—
Food Slicers	M	—	Gear	Constant	Open/Enclosed	—	Split-phase	—	—
Ventilating Fans Unit Heaters	L	Quiet	Direct	Usually Constant	Drip-proof Enclosed	—	Split-phase	Perm.-split Capacitor	—
Organ Blowers	L	Quiet	Direct	Constant	Drip-proof	—	Split-phase	Cap.-start Perm.-split	—
Sewing Machines	M	—	Belt	Constant	Drip-proof	—	Split-phase	—	—
Hoists	M	—	Gear	Constant	Enclosed	Reversing	Cap.-start	—	—
Milk Floats Trucks	M	—	Gear	Adjustable	Drip-proof	Reversing	D.C. Compound	—	—
Potato Peelers	M	—	Gear	Constant	Open/Enclosed	—	Split-phase	Cap.-start	—
Food Mixer	M	—	Gear	Constant	Open	—	Split-phase	Cap.-start	—
Lathes	M	—	Gear	Constant/ Adjustable	Open	Reversing	Cap.-start	Split-phase D.C.	Continuously adjustable speed sometimes obtained by D.C. motor fed from rectified A.C. supply.
Domestic Applications									
Food Mixer	M	—	Gear	Constant	Open	No	Universal	—	—
Floor Polisher	M	—	Gear	Constant	Open	No	Universal	—	—
Vacuum Cleaner	L	—	Direct	Constant	Open	No	Universal	—	—
Spin Drier	M	—	Belt or Direct	Constant	Open	No	Universal	Perm.-split capacitor	Use of perm-split cap. motor directly mounted will reduce choice of gyrator speed—is popular on Continent.
Washing Machine	M	—	Belt or Direct	Constant	Open	No	Split-phase	Shaded-pole or perm.-split	Alternatives usually found on washing machines not using power-driven wringers.
Circulating Pumps	M	Quiet	Belt or Direct	Constant	Open	No	Split-phase	Cap.-start	Cap.-start sometimes useful to reduce light flicker. Pipe system often tends to transmit noise.
Oil Burner	M	Quiet	Direct	Constant	Open/Enclosed	No	Split-phase	—	Not usually T.E. in Europe but N.E.M.A. requirement in U.S.A.
Hedge Trimmer.	M	—	Gear	Constant	Open	No	Universal	—	For safety, desirable to run off low voltage (transformer fed).
Small Fan	L	Quiet	Direct	Constant/ Adjustable	Open/Enclosed	No	Shaded-pole	Perm.-split capacitor	Both suitable for adjustable speed by resist., autotransformer or choke.
Gramophone Motor	L	Quiet	Friction or Gear	Constant	Open	No	Shaded-pole	Perm.-split capacitor	Constant speed to reduce "WOW" a prime consideration.
Coffee Grinder	H	—	Gear	Constant	Open	No	Universal	—	—
Waste Disposal Unit	H	—	Gear	Constant	Open	No	Split-phase	Universal	—

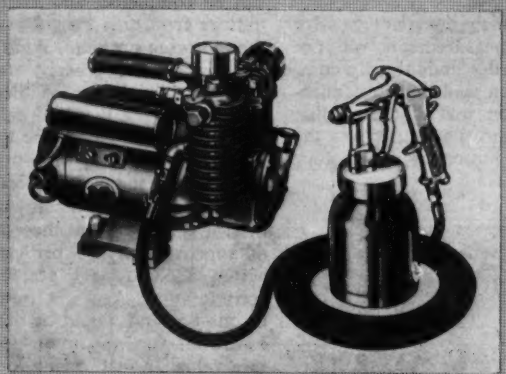
Starting Torque Key — H—High. M—Medium. L—Low.

Note on Enclosure. Very often there is a choice open to the user, depending on his own particular construction. "Open" indicates any construction with free air ventilation.



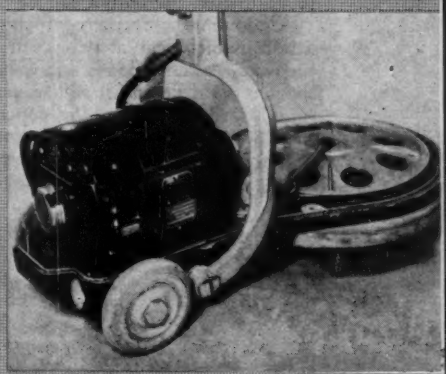
Above: Hoover f.h.p. motor (capacitor-start, flexibly-mounted) on an accounting machine.

Left: Brook f.h.p. motor, fitted with a flexible drive, in a machine for inserting single tufts in carpets.

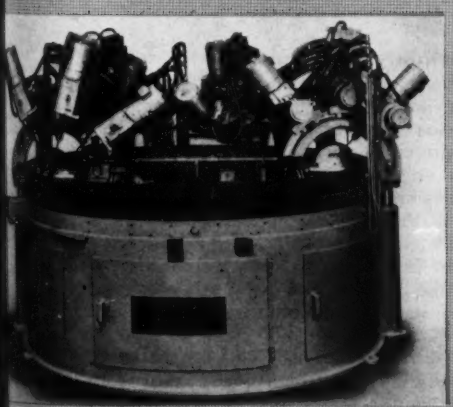


Above: Crompton Parkinson f.h.p. motor (capacitor-start, solid-foot mounted) fitted to a Broom & Wade portable air compressor.

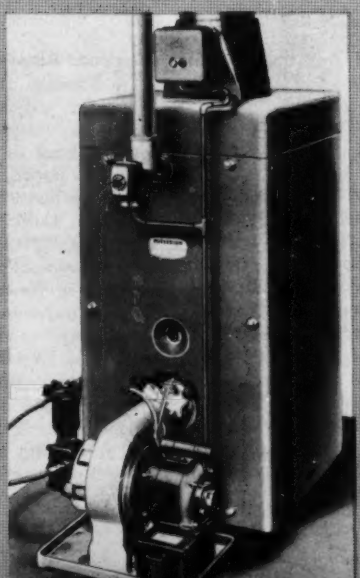
Left: Crompton Parkinson f.h.p. motor (totally enclosed) in a Harris Engineering gas unit heater.

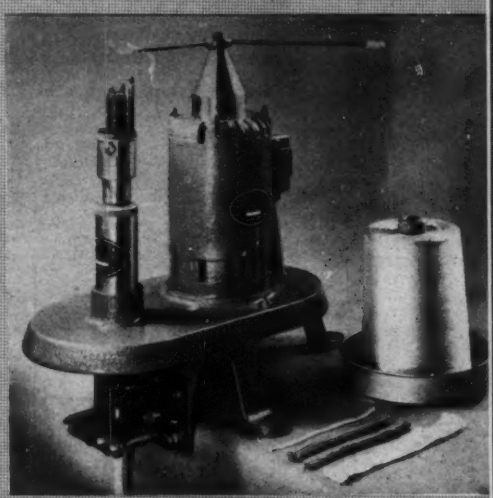


Above: B.T.H. f.h.p. motor (solid foot mounting) in a domestic appliance.



English Electric f.h.p. motors (face-mounted) in a Gaston Marbaix shoe drilling machine.





Above: Brook f.h.p. motor (face mounted) on Reader Hand cording machine.

Left: B.T.H. f.h.p. motor (capacitor-start, solid-foot mounting) driving the impeller on a "Selectos" domestic oil burner, fitted to a Potterton boiler.

final temperature, the actual time being dependent not only on the motor itself and its heat dissipation, but also the mounting, ambient conditions, etc. It is generally taken to be an approximation to an exponential rise. Let us assume however that temperature rise (at any time) is proportional to the watts loss. To a first order, a motor which can normally produce, say, ½ h.p. continuously rated, will be able to deliver roughly twice that amount one-hour rated. Below one hour the increased output rises—subject to the obvious natural limits—roughly in inverse proportion to the time rating.

Reversing duty—in so far as it affects choice of a rating—complicates everything. Information must be given as to whether the motor is allowed to come to a halt naturally, by external braking, or is to be plug-reversed. Clearly if a motor is already under full load conditions running at its maximum temperature rise, in theory no extra starts or reversals are allowable and, in fact, it is only because most machines run somewhat under their allowable rise that extra starts and reversals are permitted. As a very rough guide it may be said that if a motor can tolerate say N starts/min, it can also tolerate ¼ N plug-reversals. Most firms however will readily supply information on this subject for any particular rating, but it will be appreciated that as the inertia of all moving parts affects the answer, the query is not one for the motor designer alone.

OVERLOAD PROTECTION—Efficient in-built over-load protection can be supplied by most firms for single-phase induction motors. It is not normally required for permanent-split or shaded-pole motors, nor is it normally customary to provide such protection on any motors rated at, say, below ½ h.p. Many types of motor starter incorporate a form of overload current protection.

QUIETNESS—F.h.p. motors as generally supplied in standard ranges, operate with a good degree of quietness, it being customary to balance mechanically all rotating parts and take great pains by choice of suitable slot-combinations, etc., to minimise electrical noise and prevent resonance. Certain firms provide extra-quiet ranges of motors for the specialist—but in the last resort much always depends on the mounting and rigidity of the customer's apparatus. Single-phase motors for best results should always be mounted resiliently, and noise on induction motors can often be further reduced by provision of a suitable run-capacitor.

BEARINGS—The majority of f.h.p. motors for industrial and domestic use are fitted with sleeve bearings. They are relatively quiet in service and are now often capable of running unreplenished for the lifetime of the motor when it is on intermittent service, and with small annual increments of oil if the duty is continuous. Many modern motors are so constructed that they can be tilted to any angle and still retain their reserve of oil.

As an alternative, but somewhat more costly, ball bearings are generally available. These bearings are somewhat noisier than sleeve bearings, but this is of no importance on applications such as machine tools, etc., where the surrounding noise level is high. One restriction of sleeve-bearing motors is that their amount of axial thrust is generally limited and a considerably greater load can be tolerated on a ball-bearing machine.

The above remarks apply more to the larger types of f.h.p. motor, say, from 1/10 h.p. upward. There is no sharp division, but for smaller motors than this, particularly of a slightly lower quality, sintered self-aligning bearings will frequently be found.

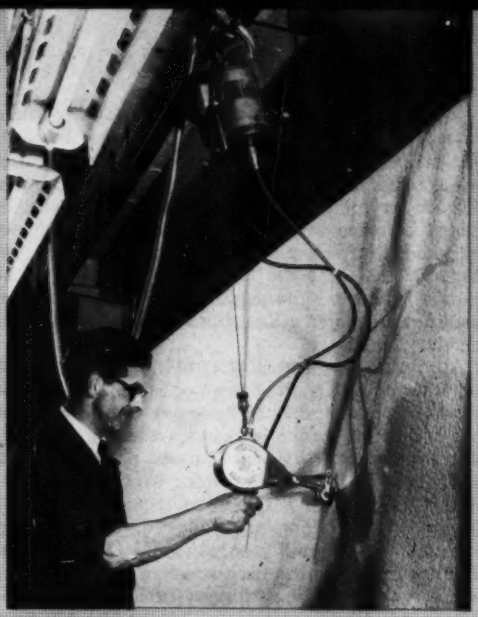
TYPE OF DRIVE—Some indication of type of drive will be required for a new application. Many applications,

TABLE I —Examples of applications for f.h.p. motors.

APPLICATION	STARTING TORQUE	NOISE REQUIREMENT	METHOD OF DRIVE	SPEED CONST. OR ADJUSTABLE	USUAL MOTOR ENCLOSURE	REVERSALS	POSSIBLE TYPES OF MOTOR		
							USUALLY	SOMETIMES	REMARKS
Industrial Applications									
Small Office Machinery	M/L	Usually quiet	Gear/Belt	Constant	Open	—	Split-phase	Perm.-split Universal	Universal not always suitable due to low noise requirements.
Air Compressor	H	—	Direct/Belt	Constant	Drip-proof	—	Cap.-start	—	—
Refrigerator	H	—	Belt	Constant	Drip-proof	—	Cap.-start	—	—
Food Slicers	M	—	Gear	Constant	Open/Enclosed	—	Split-phase	—	—
Ventilating Fans Unit Heaters	L	Quiet	Direct	Usually Constant	Drip-proof Enclosed	—	Split-phase	Perm.-split Capacitor	—
Organ Blowers	L	Quiet	Direct	Constant	Drip-proof	—	Split-phase	Cap.-start Perm.-split	—
Sewing Machines	M	—	Belt	Constant	Drip-proof	—	Split-phase	—	—
Hoists	H	—	Gear	Constant	Enclosed	Reversing	Cap.-start	—	—
Milk Floats Trucks	H	—	Gear	Adjustable	Drip-proof	Reversing	D.C. Compound	—	—
Potato Peelers	M	—	Gear	Constant	Open/Enclosed	—	Split-phase	Cap.-start	—
Food Mixer	M	—	Gear	Constant	Open	—	Split-phase	Cap.-start	—
Lathes	M	—	Gear	Constant/ Adjustable	Open	Reversing	Cap.-start	Split-phase D.C.	Continuously adjustable speed sometimes obtained by D.C. motor fed from rectified A.C. supply.
Domestic Applications									
Food Mixer	H	—	Gear	Constant	Open	No	Universal	—	—
Floor Polisher	M	—	Gear	Constant	Open	No	Universal	—	—
Vacuum Cleaner	L	—	Direct	Constant	Open	No	Universal	—	—
Spin Drier	M	—	Belt or Direct	Constant	Open	No	Universal	Perm.-split capacitor	Use of perm-split cap. motor directly mounted will reduce choice of gyrator speed—is popular on Continent.
Washing Machine	M	—	Belt or Direct	Constant	Open	No	Split-phase	Shaded-pole or perm.-split	Alternatives usually found on washing machines not using power-driven wringers.
Circulating Pumps	M	Quiet	Belt or Direct	Constant	Open	No	Split-phase	Cap.-start	Cap.-start sometimes useful to reduce light flicker. Pipe system often tends to transmit noise.
Oil Burner	M	Quiet	Direct	Constant	Open/Enclosed	No	Split-phase	—	Not usually T.E. in Europe but N.E.M.A. requirement in U.S.A.
Hedge Trimmer.	M	—	Gear	Constant	Open	No	Universal	—	For safety, desirable to run off low voltage (transformer fed).
Small Fan	L	Quiet	Direct	Constant/ Adjustable	Open/Enclosed	No	Shaded-pole	Perm.-split capacitor	Both suitable for adjustable speed by resist., autotransformer or choke.
Gramophone Motor	L	Quiet	Friction or Gear	Constant	Open	No	Shaded-pole	Perm.-split capacitor	Constant speed to reduce "WOW" a prime consideration.
Coffee Grinder	H	—	Gear	Constant	Open	No	Universal	—	—
Waste Disposal Unit	H	—	Gear	Constant	Open	No	Split-phase	Universal	—

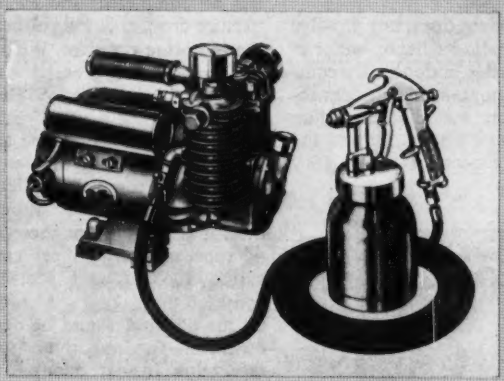
Starting Torque Key — H—High. M—Medium. L—Low.

Note on Enclosure. Very often there is a choice open to the user, depending on his own particular construction. "Open" indicates any construction with free air ventilation.



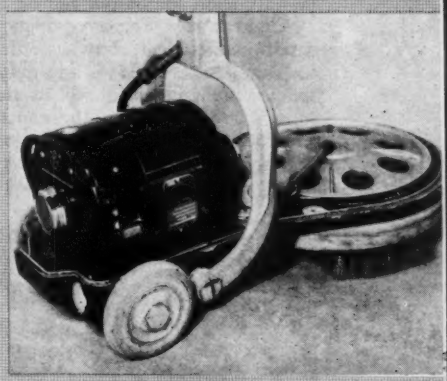
Above: Hoover f.h.p. motor (capacitor-start, flexibly-mounted) on an accounting machine.

Left: Brook f.h.p. motor, fitted with a flexible drive, in a machine for inserting single tufts in carpets.

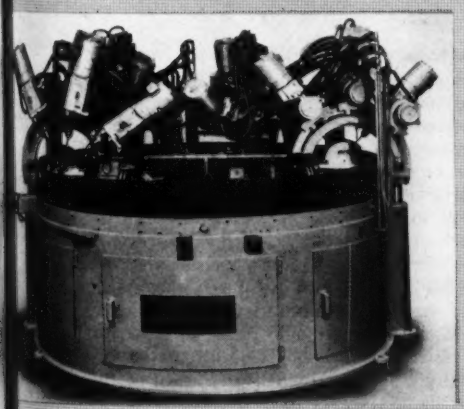


Above: Crompton Parkinson f.h.p. motor (capacitor-start, solid-foot mounted) fitted to a Broom & Wade portable air compressor.

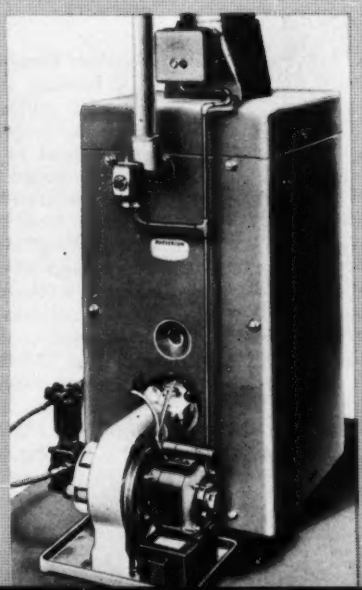
Left: Crompton Parkinson f.h.p. motor (totally enclosed) in a Harris Engineering gas unit heater.

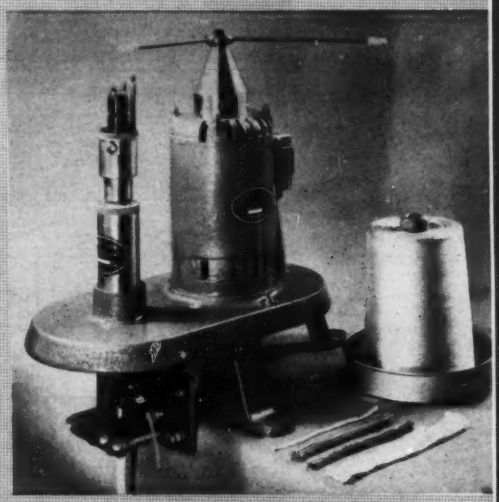


Above: B.T.H. f.h.p. motor (solid foot mounting) in a domestic appliance.



English Electric f.h.p. motors (face-mounted) in a Gaston Marbaix shoe drilling machine.





Above: Brook f.h.p. motor (face mounted) on Reader Hand cording machine.

Left: B.T.H. f.h.p. motor (capacitor-start, solid-foot mounting) driving the impeller on a "Selectos" domestic oil burner, fitted to a Potterton boiler.

e.g., fans, are directly mounted, in which cases it may be required to know the weight and position of the fan runner. Belt drives may produce a substantial radial pull, and certain applications will profit by adopting the automatic belt-tensioning cradles to reduce belt slip and wear.

APPEARANCE AND STYLE—Contrary to general belief, most engineers have an eye for beauty, and other things being equal will undoubtedly choose a motor of clean outline and pleasing appearance.

While many motors are installed out of sight and the aforesaid remarks may not apply strictly to them, for those applications where the motor is visible and may quickly attract dirt, a smooth exterior and an avoidance of ugly protruberances or cable loops (so common on capacitor motors) are obvious advantages.

MEASUREMENT OF LOADS AND TORQUES—It is now proposed to make a few remarks about simple measurements and to discuss the characteristics of the domestic washing machine as an example.

If it is known that load is constant, or nearly so, and no data is available to determine its value, the best method of measurement is to use a calibrated a.c. or d.c. motor, that is to say, a motor whose efficiency over the working range is known. Then, for a given input, as recorded on a wattmeter, the output can be obtained.

Undoubtedly, for a company which does not involve itself in electrical activities, such measurements will not be easy. Pulsating loads and duty cycles undoubtedly complicate the issue and it will be remembered that in connection with duty cycles, the conclusion was that providing the individual loads and duration were known, it was the motor designer's job to suggest a motor of satisfactory rating.

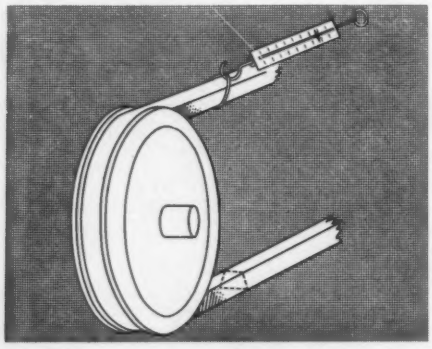


Fig. 1. Measuring torque with spring balance.

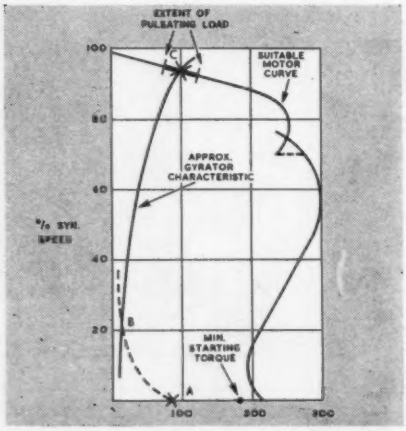


Fig. 2. Speed/torque graph for washing-machine motor.

Measurements of starting torque by spring-balance will provide useful data, and Fig. 1 shows this being done by belt drive. Obviously, in carrying out the test, care must be taken to ensure that the simple mechanical considerations for a correct reading are fulfilled. Several readings should be taken with the equipment in different positions, and the test carried out only after the equipment has been standing still for some time. If the full-load torque and starting torque for the appliance is known, it is frequently possible to make an estimate of the torque demand between the two points.

All manner of water agitators can be employed but, for the moment ignoring the torque required to overcome stand-still friction, they all have one thing in common, and that is that the torque increases according to some power of the speed with the actual index probably varying between 2·5 and 3. Its precise value is not important, as will be seen. Fig. 2 shows the speed/torque graph for such a machine with starting and full-load torque indicated by crosses. In all probability, once the initial stiffness is removed after the appliance has been standing still for a period, the high torque of starting will very rapidly drop as speed increases indicated approximately by the line AB. From B to C, employing the relationship suggested above, the curve can be completed, and even if there is a considerable departure from this line in practice, it will not greatly affect the motoring problem. What motor should then be used for the application? Clearly, attention to starting friction will ease that particular problem, but for the characteristic drawn in Fig. 2 it would be reasonable to ask for a motor with a minimum of twice the starting torque shown. This would approximate to 180 per cent f.l.t. Such a value is well within the capabilities of a split-phase motor and would provide protection against severe voltage drop. Further, it is known that these machines take a pulsating load of approximately 25 per cent above and below the mean value as could be expected from commonsense physical consideration. Again, a minimum of twice the maximum torque demand would be desirable and a figure of 250 per cent f.l.t. for maximum torque would be a reasonably safe value. In fact, owing to the occasional excess demands of a power wringer (whose torque demand is roughly constant at all speeds) and because peak loads could be experienced even above the figure mentioned, maximum torques of 280 per cent are more usual. However, there is a certain amount of latitude and with the different characteristics of washing machines, one figure may well be as good as another. Modern practice, however, is to provide, as has been shown, very considerable excess torque over the normal demands of the appliance. This at first sight may seem uneconomical, but if operation is to be satisfactory experience shows these high torque margins to be necessary.

Typical Applications

A number of typical domestic and industrial applications are indicated in Table 1. There are a number of specialised applications among them, but most of those quoted tend to represent a certain class of applications, and it is hoped that engineers will be able to find amongst them at least one which closely approaches their own problem. Looking at the domestic applications, it will be seen that, as might well be expected, a high proportion of this equipment is motored by what may be called cheap sources of power; there is undoubtedly a tendency to go to, say, universal or shaded-pole motors wherever possible, as opposed to the more expensive split-phase or capacitor machines. On the other hand, it will be seen that industrial applications utilise the more expensive types of motor.

To indicate how manufacturers have overcome specific problems several illustrations are shown on page 81.

The column referring to starting torque (Table 1) is an

TABLE 2.—Manufacturers of f.h.p. motors for general domestic and industrial use.

COMPANY	SPLIT-PHASE	CAP.-ST. & CAP.-RUN	PERM.-SPLIT	SHADED-POLE	R.I.	POLY-PHASE	UNIVERSAL A.C./D.C.	D.C.	FURTHER ITEMS OF GENERAL INTEREST	ADDRESS
Andec	✓	✓	✓	✓	—	✓	✓	✓	All up to 1/4. h.p.	Bennet Road, Reading.
B.K.B. Electric Motors	1/10-1/3	—	1/1000-1/20	—	—	1/10-1/2	1/100-1/8	1/20-1/2 a	a. Min. h.p. 1/150 for series and shunt. Geared units.	Luton, Bedfordshire.
B.T.H.	1/40-1/2	1/40-1 1/2	1/40-1	1/200-1/10	—	1/10-1 1/2	1/50-1/3	1/100-1 1/2 a	Geared units. Flameproof motors. Stator/rotor units for refrigeration. Starters, etc. a. Series 1/40-1/2. Shunt 1/100-1 1/2 Compound 1/8-1 1/2.	Rugby, Warwickshire.
Brook	1/10-1/2	1/10-1/2	—	—	—	1	—	—	Includes general purpose range. Starters.	Empress Works, Huddersfield.
Crompton Parkinson	1/8-1/2	1/8-1 1/2	1/8-1/3	—	—	.95	—	1/20-1 1/2	Geared units. Super-silent range. General purpose motors. Flameproof motors. Air stream range. Ceiling fans.	Crompton House, Aldwych, London W.C.2.
Croydon Eng. Co.	✓	1	1	18w.	—	1 1/4	1 1/4	1 2/3	N.B. All h.p. ratings up to those shown. Geared units. Synchronous motors.	Commerce Way, Purley Way, Croydon, Surrey.
Delco	1/2	1/3	—	Approx. 25w.	—	✓	1/4	—	Stator/rotor units for refrigeration.	Dunstable, Bedfordshire.
Electrical Power Co. (Birmingham)	—	—	—	—	—	—	—	1/8-1		Bromford Lane, Birmingham, 8.
English Electric	1/20-1/2	1/20-1	—	—	—	1/20-0.95	—	1/20-1		Marconi House, Strand, London. W.C.2.
F.H.P. Motors	1/20-1/4	—	1/80-1/6	1/160	—	1/16-1/3	1/250-1/4	1/250-1/4 a	a. Shunt series } only, no compound.	The Hyde, Hendon, London, N.W.9
G.E.C.	1/40-1/2	1/8-1	1/40-1/10 a	—	1/4-7/8	1/6-0-95	1/60-1/6	1/4-1 b	a. To special requirements. b. Compound only, shunt special, geared units ceiling and desk fans. Starters, etc. Stator/rotor units for refrigeration.	Magnet House, Kingsway, London. W.C.2.
Hillman Elec.	—	—	1/100-1/10	1/200-1/75	—	1/25-1/4	1/200-3/4	1/200-1/2 a	a. Except series 1/200-3/4.	Grange Grove, London, N.7
Hoover	1/6-1/2	1/6-1/2	—	1/20-1/4	—	1/6-3/4	—	—	Stator/rotor units for refrigeration.	Perivale, Greenford, Middlesex.
Howells (Electric Motors)	—	—	—	—	—	✓	—	—		Vale Place Works, Hanley, Stoke-on-Trent.
Klaxon	1/4-1/2	1/2000-1/10	1/2	1/1500-1/30	—	1/40-1	1/100-3/4	1/100-1 a	a. Max 3/4 in case of d.c. series motors. Geared motors.	Upper Brook Street, London. W.1.
Lancashire Dynamo	✓	✓	✓	—	✓	✓	—	✓	All up to 1 h.p.	St. Stephens House, Victoria Embankment, London, S.W.1.
Laurence Scott	—	—	—	—	—	1/4-3/4	—	1/8-1		Manfield House (4th Floor), Southampton Street, London. W.C.2.
M.G. (Electric)	0-1/2	0-1/2	—	up to 1/100	up to 1 1/2	up to 2	1 3/4 a	up to 3/4	a. Special for concrete vibration.	Hawkins Road, Colchester, Essex.
Morley Elec.	—	a ✓	—	—	—	—	—	—	a. Flameproof.	Troy Works, Stanningly, Leeds.
Motor Electrics	1/100-1/8	1/100-1/8	1/100-1/8	1/100-1/8	—	1/100-1/8	1/100-1/8	1/100-1/8	Geared units.	Crown Lane, Marlow, Bucks.
Metropolitan Vickers	1/40-1/2	1/40-1 1/2	1/40-1	1/200-1/10	—	1/10-1 1/2	1/50-1/3	1/100-1 1/2 a	a. Geared units. Flameproof motors. Stator/rotor units for refrigeration. 1. Series 1/40-1/2. Shunt 1/100-1 1/2. Compound 1/8-1 1/2.	Trafford Park, Manchester.
Nelson Engin. Co.	up to 1 a	up to 1	up to 1	—	—	up to 1	up to 1/3	up to 1	a. This is exceptionally high for a split-phase motor (Author).	Netherfield Road, Nelson, Lancs.
Newman	1/16-1/2	1/16-1/2	1/16-1/2	—	—	1/6-1	—	—	Flameproof motors as well as standard enclosures.	Yate, Bristol.
Parvalux	up to 1/8	up to 1/8	—	up to 1/20	—	up to 1/50	up to 1/6	up to 1/10 a	a. No compound and series, 1/6 h.p. max.	Parkstone, Poole, Dorset.
Small Electric Motors	1/8-1/3 a	1/6-1 1/4	1/50-1/4	1/200-1/100	—	1/4-2	1/4, 1/3 and 1	1/4-1/2	a. Special to customers' demands, geared units.	Beckenham, Kent.

✓ = denotes manufacture in unspecified range

NOTE: With the exception of a.c./d.c. (universal) motors, figures for h.p. range refer to a rating of approx. 1,425 r.p.m. drip-proof. This has not been explicitly stated in all manufacturers' data, but from the actual values of h.p. quoted, it has seemed reasonable to assume this is so. It should be appreciated that for lower speeds and particularly for T.E. motors, the actual frame-size required, say, for a 1-h.p. motor will be very much larger than the 1,425 D.P. 1-h.p. machine. For this reason, manufacturers tend to limit their largest physical frame-size in the f.h.p. range to D.P. 1 h.p. dimension. There is clearly some ambiguity about the curent terms for different types of motor. One case where this is particularly so is between cap.-start/cap.-run and perm. split capacitor motors.

attempt only to indicate the actual starting torque physically required by the application as opposed to that produced by the motor. It is impossible to produce hard and fast ranges of torque for the three categories, low, medium and high, referred to, but approximate values would be:

Low starting torque up to 25 per cent f.l.t.

Medium starting torque from 25-100 per cent f.l.t.

High starting torque from 100-250 per cent f.l.t.

The equivalent terms as applied to torque actually produced by motors have been already indicated in the first part of this article, and some idea will thus be obtained of the differences between motor and application torques. It would probably be right at this stage to make mention of the importance of the minimum accelerating torque produced by motors as, particularly for split-phase and shaded-pole motors, this may well be slightly below the nominal value of starting torque produced. The minimum accelerating torque generally occurs in the region of one-third of the synchronous speed of the motor.

Even with the data and information that has been given in both parts of this article, the designer must still, however, have a thorough understanding of his own product and not shirk the careful analytical work in determining in quantitative terms as much information on the load requirements as possible.

ALUMINIUM STRIP AND FOIL FOR COIL WINDINGS

An examination of the developing use of aluminium strip and foil for coils and transformers, and the changing economic pattern according to the relative prices of aluminium and copper

by D. WORTH, B.Sc. (Eng.), A.M.I.E.E.*

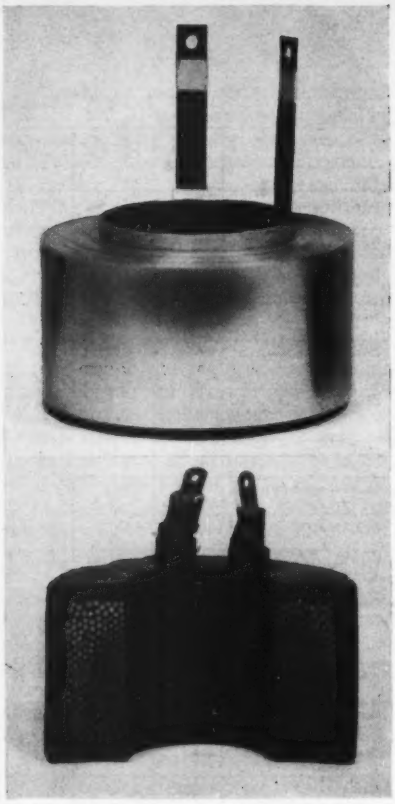


Fig. 1. Comparison of foil and wire-wound coils.

ALUMINIUM foil and strip windings for electrical coils and transformers have, in recent years, aroused great interest among the more progressive manufacturers in this country and the U.S.A. for two main reasons. The first, and perhaps most important, is an economic one; the second is technical. Interest has, in turn, led to development work on the various aspects which arise, and this has been carried on, in the U.S.A. particularly, to the further stage of commercial production.[1]

In conventional coil winding up to the present time, copper wire of round cross-section has been used in the smaller sizes, and that of square or rectangular section for larger coils. If copper wire is replaced by aluminium wire of equal conductivity, adjustments must be made in the rest of the machine, to take account of the increased bulk of conductor material, if the same overall characteristics are to be maintained. This would generally involve an increase in the quantity, or, where possible, the quality, of the magnetic core material. Furthermore, the scales are further weighted against aluminium conductors of conventional form by the economics of wire production, where the cost of converting aluminium into wire is higher per unit weight of wire than the corresponding process for an equal weight of copper. Thus it is generally found that the overall cost of the aluminium wire wound machine is greater than its copper counterpart.

Between the turns and layers of round wire there are unavoidable air spaces. It is by eliminating these and, in some cases, by reducing the amount of insulation, that aluminium can be used to produce a winding and, hence, a complete machine, which will occupy the same or even less space, and cost less, than its copper counterpart. In brief, this is effected by using an aluminium foil or strip conductor, which has the same conductivity per unit length as the copper wire it is replacing, and whose width is equal to that of the coil in question.

While material cost has been emphasised as a major factor in the development, it should be stressed that reduction in production costs was also one of the reasons leading to the development of foil and strip windings. A coil construction was sought, which in all its aspects was amenable to automatic production techniques and some remarkable reduction in production costs would appear to be possible.[6]

ADVANTAGES OF FOIL AND STRIP—It is now proposed to enumerate and briefly discuss the advantages of foil and strip coils:

(a) Winding problems are simplified; since each layer consists of only one turn, the traversing complications of a conventional winding machine are not needed, and bobbins and flanges can often be eliminated. Also, the work of making tappings and bringing out coil ends can be very much easier than with wire coils and, eventually, there is no reason why all these operations should not be done automatically and at speed.

(b) Adjacent layers of a strip winding have only turn-to-turn voltage between them, and thus the thicker inter-layer insulation associated with a round wire winding is eliminated. For example, the inter-turn voltage for a strip winding may be one volt compared with an inter-layer voltage of a wire winding as great as 50 volts.

(c) In some situations, the performance of a transformer under surge conditions is important, and here the behaviour of a strip wound coil is likely to be better than that of a conventional coil due to the greater interturn capacitance. This will give greater penetration of the surge, with a reduction in surge volts per turn over the first few turns.

(d) As previously mentioned, there are virtually no air spaces in the winding and this means that it may occupy the same or even less space than its copper wire counterpart.

(e) Foil and strip windings, particularly when anodised material is used, have been found to have excellent heat transfer characteristics. This is due to the elimination of air spaces and the fact that each turn usually extends the full width of the coil; thus heat can pass easily in all directions through the winding. Hot spots do not develop and if

* *Lecturer in electrical engineering, The Polytechnic, London.*

temperature rise is the criterion of design, smaller aluminium cross sections can be used than required on the basis of equal electrical conductivity. Furthermore, short time overloads can, for the same reason, be safely withstood, and machines can be designed on the basis of their normal rating.

(f) The practice of impregnating windings to exclude moisture has been considered unnecessary—and, by some, even impossible—with strip windings. By eliminating one production process, this would obviously help to reduce costs.

(g) The technique of foil and strip winding is obviously not fundamentally restricted to aluminium, and copper foil has, indeed, been considered.[6] However, up to the present time, aluminium foil and strip are cheaper than their copper counterpart, partly because of the smaller existing demand for copper foil, and partly because of the greater production difficulties associated with rolling it.

METHODS OF MANUFACTURE—Methods of winding already tried include two distinct techniques; either the coils can be wound separately or they can be sliced from a longer coil. This latter method, known as the "wafer coil" technique,[6, 7, 8] has been applied to 0.00017 in. thick aluminium foil to produce wafers 0.018 in. thick, and at the present time has been extended to produce coils up to 24 in. diameter and 24 in. wide.[12] Separately-wound coils have been produced from material 0.008 in. thick and 3¾ in. wide. The choice of method depends partly on the insulation used as well as on the obvious question of relative costs.

The wafer coil technique has been developed in three main ways,[8] known as the wind-slice, the wind-slit and the slit-wind methods (see Fig. 2).

In the wind-slice method, wide foil is wound into a roll after having been (a) coated with an insulator before coiling, or (b) coiled with interleaving insulating paper, or (c) coiled with spacers between turns to permit subsequent impregnation. The wide foil coil is then sliced into wafers

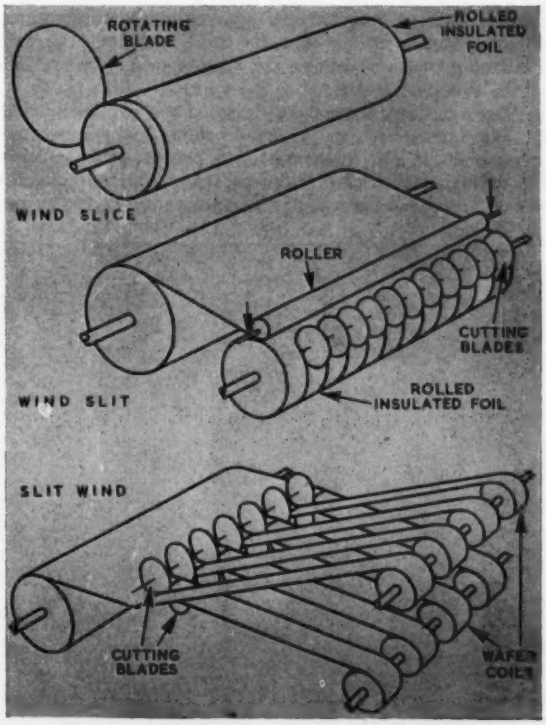


Fig. 2. Three methods of producing wafer coils.

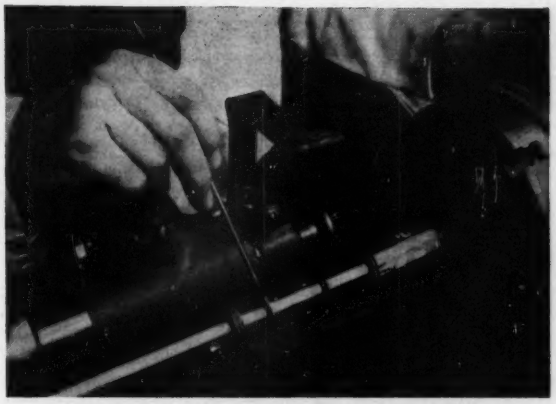


Fig. 3. Slicing of wafer coils using a rotary blade.

on a lathe type machine using a straight blade or a rotating circular blade, as shown in Fig. 3.

As the knife tends to smear the edges of the foil and short-circuit the turns, a chemical etch, to dissolve the rough edges, followed by a wash, is necessary. In a particular case,[7] after drying, the wafer coils were insulated by spraying. Jointing to the coil ends was made possible at the start and finish by winding tinned copper foil in with the aluminium for the first and last few turns. To facilitate soldering, a tinned copper tube was also included in the roll of foil before winding began; at the finish a tube was included below the final turn, or the tinned copper foil was folded back upon itself to form a terminal tab. The long lap joint produced a good contact with low electrical resistance. Nowadays, these methods of terminating would not be favoured, and cold pressure welding, or ultrasonic welding would be used. Another simple method is to slit the end of the foil or strip and by folding the slit ends at right angles, to form a thicker laminated foil terminal lead.

The wind-slit method is similar to the wind-slice method, but it is said to have the important advantage of generally eliminating the smeared edges of the wafer. In this method, the wide foil, insulated as before, is wound into a roll, but before the foil has completed one turn it is slit by a rotary blade, which extends into the roll for only a few layers. This reduces the tendency of the edges to smear, but even so some burrs remain which require etching, although the amount is much less and the uniformity much greater than in the wind-slice method. The wind-slit method is, apparently, limited to foils of 0.001 in. maximum thickness, but enables the wide roll to be reduced to wafers in one operation.

Slit-wind Technique

The slit-wind technique, in effect, makes insulated ribbon before winding. It is very flexible and enables terminal and intermediate tapping leads to be attached to the ribbon before the wafer is wound. The method has been developed for use with coated foil, but there would appear to be no objection to the use of interleaving insulation. Besides making the attachment of tapping leads easier, this method makes available the individual edges of the ribbon, between cutting and winding, for the removal of burrs.

Single-coil winding has been applied in general to wider foil and strip insulated in a number of ways.

THE ALUMINIUM ITSELF—Before discussing the important matter of insulation, the subject of the aluminium itself should receive attention. In this country, the dividing line between foil and strip is generally considered to be at a thickness of about 0.006 in. When a particular conductor cross section is required, it is obviously possible to use a

wide thin foil or a narrower thicker strip, the number of turns and the total winding cross section being the same in each case. The final choice will be dictated by the relative costs of the two conductors when insulated. This, of course, assumes that the size of the rest of the transformer remains the same in each case.

In this country, aluminium foil has been produced mainly of 99 per cent purity aluminium and mainly in the annealed condition.[9] A large percentage of this has been consumed by the packaging industry, and a smaller percentage, and also some higher purity foil, by the electrical industry, for the manufacture of capacitors. These consumers, in fact, dictate the purity, thickness and temper of present production.

In using foil as a conductor, one has to consider purity of material primarily from the aspect of electrical conductivity, setting against this the increase in cost associated with increase in purity. It may well be that purity is relatively unimportant when one considers that the change in conductivity is from about 59-64 per cent I.A.C.S. from commercial purity to super-pure aluminium for which the price ratio may be 1 : 2. The temper of the material, which has little effect on price, may be more important, however, as it affects winding tension, the strength of the complete winding and the possibility of damage to material during storage and manufacture. All these matters are being considered, but obviously, cannot be resolved until experience has been gained by both the aluminium and electrical industries. It is of interest to note, however, that up to the present time, aluminium which has been used has been of commercial purity with conductivity in the range 59-61 per cent I.A.C.S.

Many of these factors also apply to strip, though present uses and processes are not so well defined.

Methods of Insulation

INSULATION—The methods of strip winding already outlined require the separation of consecutive layers with a suitable insulation, and this is obviously one which itself has the form of a thin layer. Among the many materials available in this form are the following three groups, the first two containing insulation of all temperature classes (of B.S. 2757)[10] and the last group being of the temperature Class C, i.e., for use above 180 deg. C.

Group 1 Insulation in sheet or strip form such as paper and Terylene.

Group 2 Deposited coatings such as an insulating resin.

Group 3 Aluminium oxide.

The first group could embrace other plastics materials, such as p.v.c., polyethylene, p.t.f.e., polystyrene, etc. The choice of material depends on a number of considerations including relative costs, available thicknesses, and electrical, mechanical and physical properties.

In the second group are included all insulants which can be deposited evenly on the aluminium surface in thin coatings. In an actual case the aluminium foil was coated before coiling with a phenol formaldehyde resin dissolved in a suitable solvent. The completed coil was then baked, resulting in a solid mass with individual turns separated by a 0.00002 in. thickness of resin. One can visualise the technique as one step in a continuous winding process, and there is no doubt that it could be applied to other insulants, using suitable solvents, and with the epoxy and silicone resins, could cater for most insulation classes.

ALUMINIUM OXIDE—Aluminium oxide has been classified on its own because of its unique properties. It has long been known that the hard natural oxide film present on aluminium is an electrical insulator, and, in fact, was the main reason for jointing difficulties. Furthermore, as an insulator it maintains its insulating properties up to very high temperatures, in fact to 1,025 deg. C. when it melts. It should be noted that aluminium melts at a temperature of about 660 deg. C.

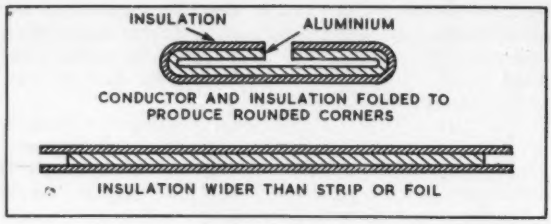

INSULATION
ALUMINIUM
CONDUCTOR AND INSULATION FOLDED TO PRODUCE ROUNDED CORNERS
INSULATION WIDER THAN STRIP OR FOIL

Fig. 4. Methods of insulating rough edges.

Electrolytic anodising processes can thicken the natural oxide film producing a coating as thick as 0.003 in.[11] with high dielectric strength. However, with usual processes, it is possible to obtain breakdown values of at least 20 volts per micron, i.e., a coating of, say, 0.0002 in. would have a breakdown strength of at least 100 volts. It should be stressed that the subject of anodising for electrical insulation is not fully developed, as it is in the case of anodising for decorative and protective purposes.

Electrical engineers' interest stems mainly from a combination of the following points:

(a) The insulation between layers of a strip or foil winding need withstand, perhaps, one or two volts, or less. This can adequately be withstood by an anodic coating of negligible thickness, thus giving a space factor of nearly unity, better than that attained with copper; this prevents the increased volume of aluminium conductor material from producing a coil with larger overall dimensions than its copper counterpart.

(b) A reduction in size of transformer is obtained by designing it to operate at a higher temperature. If copper conductor is used, it must be covered with an expensive glass braid or asbestos type insulation.[2] Anodised aluminium conductor could compare favourably in price with the insulated copper conductor.

(c) For some applications electrical machines are required to work continuously in high ambient temperatures, and here a prime example is in supersonic aircraft. Under these conditions, the advantages of the previous section also apply.

(d) Certain transformers are designed to have their windings immersed in a fire-resistant high-temperature coolant.[2, 3] Their purpose is to provide more efficient units than their class H (air-cooled) counterparts, and to compete economically with mineral-oil-cooled trans-

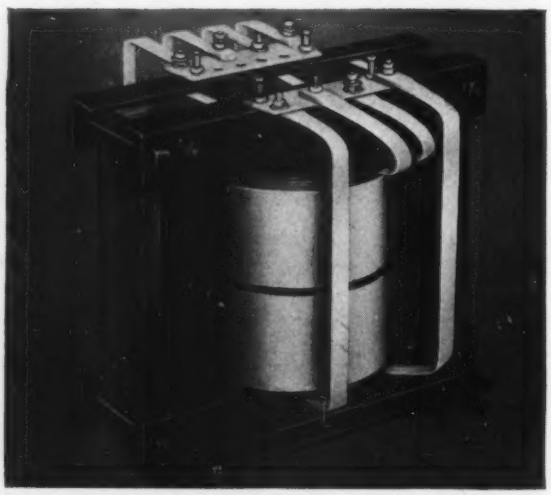


Fig. 5. 10-kVA transformer wound with anodised strip conductor.

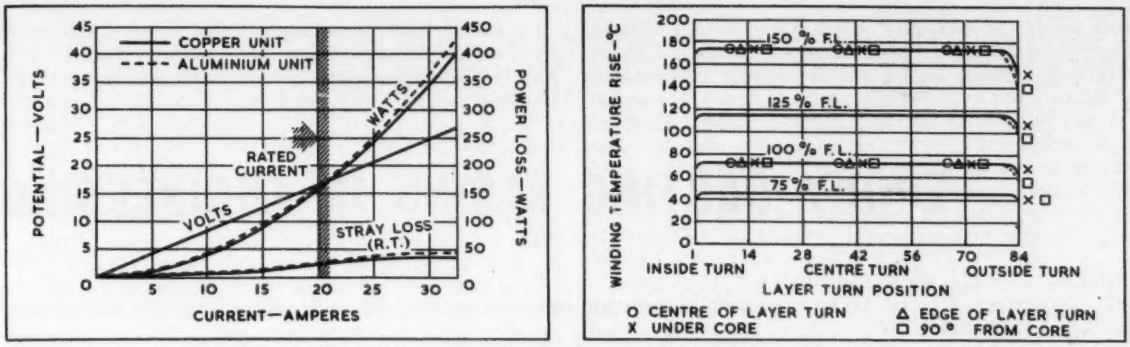


Fig. 6. Electrical and thermal characteristics of transformer in Fig. 5.

formers of the same rating. At the temperatures envisaged these coolants affect cellulosic and silicone insulations, whereas the anodic film is found to be resistant to attack and may be most suitable for this use.

(e) An important aspect of the anodic film to be borne in mind when considering it as an high-temperature insulant is its extremely good heat transmission property due to its thinness and its being an integral part of the aluminium, i.e., not only does it withstand high temperatures, but it prevents hot spots from forming.

(f) Whilst the initial cost of an electrical machine, which is a function of volume, is important, nevertheless, for use in moving vehicles such as aircraft and trains, the weight of the machine also assumes importance; this could be expressed in units of £/lb.-mile. For this reason, aluminium windings, particularly with a high-temperature insulation are important.

Finishing Edges

EDGE TREATMENT—One further requirement for material for strip and foil winding is that the edges should be either rounded or, if left square, should be effectively separated from one another. Briefly, this is because the electrical stress at the surface of a charged body is an inverse function of the radius of curvature of the surface. Thus sharp corners tend to produce a comparatively high stress, which could lead to electrical flash over between turns down the side of the winding. For material which is to be anodised, a mechanical-chemical treatment would be suitable for rounding the edges. For individually-wound interleaved material, the insulating strip should be wider than the aluminium strip, or, alternatively, this latter can be folded in the form of a flattened C as shown in Fig. 4. This ensures that the rough edges produced by slitting are safely covered by insulation, and the bending produces round edges.

JOINTING—Jointing of aluminium presents no problem nowadays and a variety of methods are available.[5] These include:

(a) Cold pressure welding: the two surfaces to be joined should be clean before they are pressed together. The operation, carried out at room temperature, results in a true weld. It is interesting to note that, contrary to expectation, an anodised film assists in producing a good cold weld.

(b) Ultrasonic welding: a comparatively recent development and involving the application of ultrasonic vibrations to the interface of the joint, which is then cold welded by a greatly reduced pressure.

(c) Electric spot welding: this is sufficiently well known to require no explanation.

(d) Soldering: while this is fully developed for aluminium, it is not proposed to enlarge on the subject here.[5]

(e) Mechanical connections: these include rivets, screws, etc., and the success of this form of joint relies on its design being such that large areas of contact are formed, producing a net low and stable contact resistance.

(f) Inert gas welding: This will have limited application in this instance, as it is generally considered more suitable for joining massive conductors of the busbar variety.

APPLICATIONS—The author considers that strip and foil winding is, perhaps, most applicable to small and medium transformer windings. For large and high voltage transformers, the mechanical strength required in the conductor material, for the time being, at least, favours copper, and the production processes involved, on the whole, rule out mass production. The wafer coil technique would probably be most suitable for the manufacture of small coils, such as R.F. coils, small instrument coils, relays, etc., whilst not precluding larger windings. These latter would, however, best be produced singly.

Fig 5 shows a 10 kVA transformer, using anodised strip, made in the U.S.A. and having the same electrical characteristics, but being lighter and costing less than its copper-wire counterpart. In Fig. 6 is shown graphically the electrical characteristics of this transformer, compared with a similar one wound with copper wire, and the temperature distribution found in the transformer.

This article has tried to present a picture of the complete development of these windings, underlining the particular aspects which must be studied from the price angle. In summary these are: conductor material cost; insulation or insulating costs; and production, including labour, costs.

It is not sufficient to consider each of the above independently when comparing two systems of construction; it may well be that a reduction in, say, labour costs is obtainable with one method justifying an apparently uneconomic material price, or *vice versa*.

The author wishes to thank the Aluminium Development Association for information and a number of the illustrations, which appeared in a paper by J. Staley of the Reynolds Metals Co. U.S.A.[1]

REFERENCES

[1] Symposium on "Aluminium in Electrical Engineering" A.D.A. (1957). "Use of Aluminium Strip Conductor in Electrical Equipment". J. Staley.
[2] A.D.A. Symposium. "The Use of Aluminium in the Construction of Transformers". F. W. Gee and R. J. Gresley.
[3] A.D.A. Symposium. Discussion of [2] Proc. p. 339. N. G. Thomas.
[4] A.D.A. Symposium. Discussion of [2] Proc. p. 355. E. G. West.
[5] A.D.A. Symposium. "Fundamentals of Jointing Processes for Aluminium". J. C. Bailey and P. Gregory.
[6] "Automatic Production of Audio Transformers". A. Zack, T. Wroblewski and W. H. Hannahs. Proc. Symposium on Automatic Production of Electronic Equipment. San Francisco (1954).
[7] "Aluminium Foil in Transformer Coils". A. Zack. *Modern Metals*. October 1954.
[8] "Basic Considerations in Foil Transformer Production". W. Brackmann, R. Levinsohn and D. McCarthy, *Electrical Manufacturing*, January 1957.
[9] "Aluminium in Packaging". A.D.A. (1957).
[10] BS 2757: 1956 "Classification of Insulating Materials for Electrical Machinery and Apparatus on the basis of Thermal Stability in service".
[11] "Hard Anodising of Aluminium and its Alloys." A. W. Brace, *Electroplating and Metal Finishing Journal*. 1954, Vol. 7, Parts 9 & 10, pp. 329-334, 376-379.
[12] "Weight Reduction Techniques in Transformer and Coil Design." T. Wroblewski. Conf. of S.A.W.E. (U.S.A.), May 1958.

EPOXY CASTING RESINS IN ENGINEERING

Among many interesting post-war developments in plastics, epoxy resins stand out for their variety of applications. This article describes one important group of applications based on the unique casting properties of the material

by P. A. DUNN and J. M. TURNER*

CHEMICALLY, epoxy resins are derived from epichlorhydrin and diphenylol propane, and are either liquids or solids which can be converted into hard, tough and resistant products by reaction with hardeners. The chemistry of the epoxy resins is very complex, but it is possible to produce mixtures of resins and hardeners for particular uses. The products may be modified with other materials, such as plasticisers and fillers, giving them an even wider range of use.

As a group, epoxy resins exhibit the following characteristic properties:

1. They cure without splitting off any volatile matter
2. They cure without the application of pressure
3. They cure with negligible shrinkage
4. Outstanding adhesion to metals, glass, porcelain, etc.
5. Excellent mechanical and electrical properties
6. Outstandingly stable.

This unique combination of properties makes them extremely versatile, and their field of use is extending rapidly and indeed there is hardly an industry in which they do not find some application.

Many different epoxy casting resins are available. These range from low viscosity liquids to hard solids, but in use, these latter materials have to be heated, when they become liquid. A range of hardeners is also available which, when combined with individual resins, enables the final properties of the casting to be modified to suit particular applications. For application the resin and hardener are mixed together, either at room temperature or at elevated temperatures as required but the resulting mixture has a limited usable life. This may range from a few minutes to hours, or even days, depending upon the particular combination of resin and hardener employed. Basically, the epoxy resin systems are cast into open moulds, using simple gravity-pouring techniques and for certain more exacting applications, such as in the electrical industry, casting may be carried out under vacuum. Moulds may be made from steel, aluminium, brass, epoxy resin, silicone rubber, p.v.c., or any material that will hold its shape at the curing temperature involved. For long runs, however, metals are invariably used. Except in the case of split moulds a slight taper should be allowed, being approximately 30 thou./in. Horizontal ledges should be avoided as these are liable to trap air. With enclosed moulds, a liberal runner should be allowed so as to facilitate the extraction of air and to take care of the initial volume shrinkage. This amounts to some 2-5 per cent, but very largely takes place in the liquid phase. Where undercuts are involved a multi-part mould is required, and it is here the flexible materials, such as silicone rubbers, are sometimes useful.

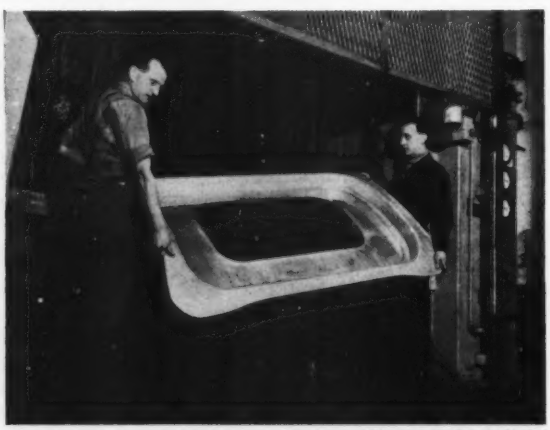


Photo: A. V. Roe & Co. Ltd.

Large sheet-metal pressing for a Vulcan bomber made with resin-cast press tools.

When designing for epoxy mouldings it is advisable to ensure that no stress points are set up by sharp edges. Corners of metal inserts should be rounded and burrs removed. Large masses of resin should not be adjacent to thin sections and differential co-efficients of expansion should be avoided as much as possible.

In order to obtain maximum adhesion to metal parts to be included in the epoxy casting, these should be thoroughly degreased before assembly into the mould.

The addition of inert fillers to epoxy resins may often be beneficial. They considerably alter the mechanical properties of a resin system without degrading the excellent electrical and chemical resistance factors. The most common fillers are silica flour, slate, marble, precipitated chalk and mica. Epoxy resins containing these fillers (with the exception of silica) can be readily machined with metal working tools. Silica, however, is cheap and is electrically very slightly superior to the others. The mesh size of a filler is important, as if it is too coarse, say larger than 100 mesh, settlement may occur, but if it is too fine an unnecessary increase in viscosity of the resin mix may result. Fillers such as mica or flaked aluminium also cause this

* *Ciba (A.R.L.) Ltd.*

latter effect due to their comparatively large surface area. The addition of metal fillers increases the thermal conductivity of the mix. Apart from the price reduction the main advantage in adding a filler is to reduce the co-efficient of expansion of a resin system. Co-efficients of 30 × 10^{-6}/ deg. C. can be readily obtained and this is extremely low for a plastic material.

Electrical Applications of Resins

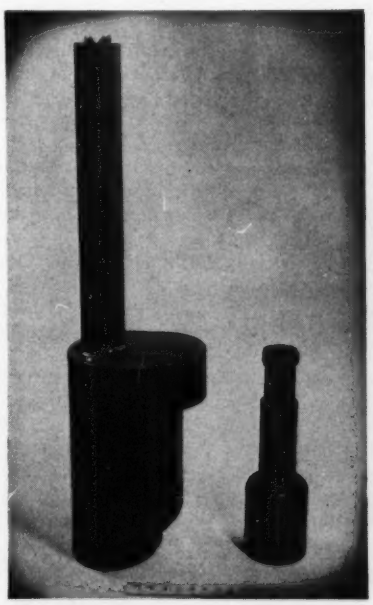
One of the most popular applications of epoxy casting resins, which typifies their use in the heavy electrical industry, is in the encapsulation of current transformers. The transformer should be designed specially for "potting", to make the best use of the epoxy resin and to avoid an unnecessarily complicated mould. To avoid breakage of the cast insulation under short circuit conditions, which heat up the copper primary winding, with subsequent expansion, the copper is sometimes first covered with resilent insulation. If the core is to be moulded in the resin it is also advisable to apply a suitable cushion directly around the core to prevent the resin from contracting directly on to it. If this precaution is not observed, the mechanical forces that may be exerted tend to affect the magnetic properties of the iron and so alter the effective turns ratio and losses of the transformer. For best results the current transformer should be cast under vacuum to prevent air being entrapped in the windings with subsequent discharge troubles. This is more important in the case of voltage transformers. Production moulds should be made of steel, aluminium or brass. In producing moulds, the design should avoid large masses of resins separated by thin sections since this may lead to cracking at the thin section caused by slight shrinkage that may take place towards the centre of the resin mass. Although the reaction shrinkage of epoxy resins after gelling is almost negligible, it may be reduced further by the addition of fillers, such as silica flour. The use of fillers also reduces the co-efficient of thermal expansion by as much as 50 per cent. This is important where an encapsulated unit will be cycled over a temperature range. The choice of the fillers affects other properties, including the viscosity of the mixture and the tracking properties of the cured product.

Since epoxy resins are excellent adhesives the mould must first be treated with a release agent. One of the most popular is a silicone material. This may be applied as a grease, a solution of a grease in a volatile solvent, or as a silicone resin stoving varnish. P.t.f.e. coatings have also been used, as well as certain high-melting point waxes. If curing takes place at temperatures below about 80 deg. C., such materials as carnauba wax or polyvinyl alcohol may be used. One point that may be mentioned here is that all moulds improve with use, and it is well worth the trouble, therefore, to apply a liberal coating of silicone grease to a new mould and to place the mould in an oven at a temperature around 200 deg. C.

At this stage it may be of interest to outline briefly the sequence of operations in the use of a casting resin. The resin most widely employed for transformers is a solid casting resin, produced under the name of Araldite B, used with a powder hardener 901. The resin is heated to about 120 deg. C. when it becomes liquid. About 200-250 per cent of silica flour is added and the mixture kept under a vacuum of approximately 3 mm.Hg. for a period to remove entrapped air. The hardener 901 is then added and stirred until dissolved. After this, a short vacuum is applied to remove the small amount of air that was introduced with the hardener. The mixture of resin, hardener and filler is then introduced into the heated mould preferably under vacuum. After this the resin is cured in the mould and is subsequently withdrawn.

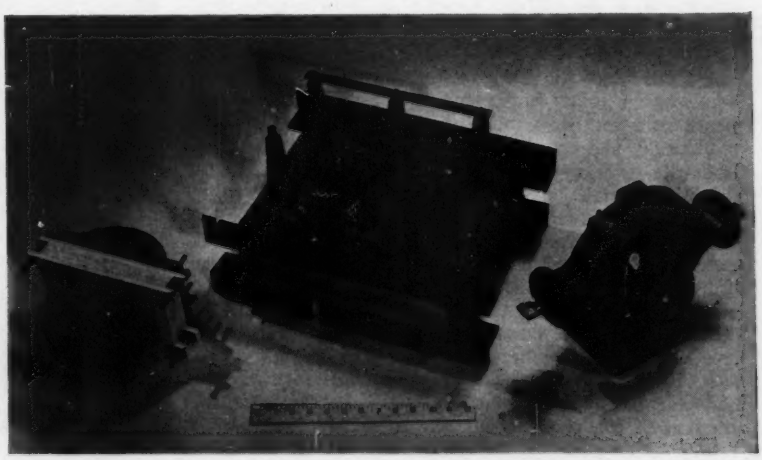
It is important that an even temperature is maintained in the oven and this is best accomplished by air circulation. Due to the fact that the shrinkage in epoxy resins takes place very largely when the resin is in the liquid phase, a useful tip is to make sure that curing of the resin takes place from the bottom upwards. This is best achieved by placing a piece of asbestos board over the riser. Complete cure of the resin need not necessarily be carried out in the mould so that half the cure can be undertaken in the mould, immediately followed by the remainder of the cure, and this allows a more rapid turnround in moulds.

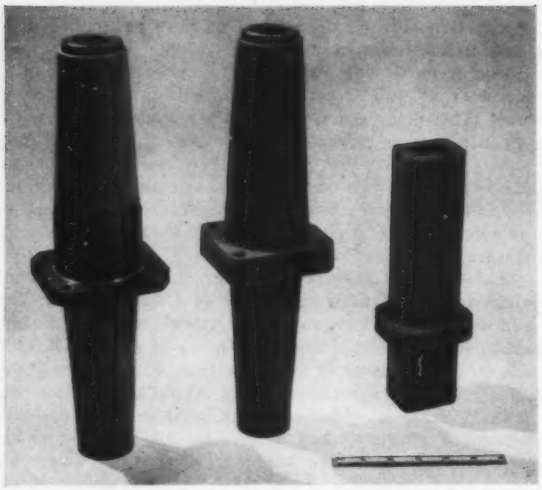
Another important application is in the manufacture of bushings. In the past these were made from porcelain or S.R.B.P. but both of these materials suffer from certain disadvantages. For example, S.R.B.P. is not resistant to water and cannot be used alone in damp atmospheres. Porcelain, on the other hand, is brittle and easily damaged in production, during installation, or as the result of short



33 kV. and 11 kV. earthing devices in filled epoxy casting resin.
Photo : South Wales Switchgear Ltd.

Transformers potted in epoxy resins. The three-phase voltage transformer (*centre*) and the current transformer (*right*) are by South Wales Switchgear Ltd. The current transformer (*left*) is by Crompton Parkinson Ltd.





Three switchgear bushings cast in Araldite filled epoxy resin (by Crompton Parkinson Ltd.).

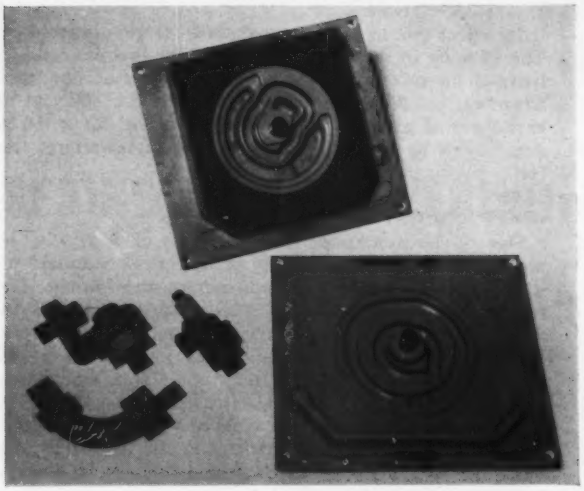


Photo: S. Russell & Sons and Ransomes Sims & Jefferies Ltd.
Pattern plates (15 in. × 13 in.) cast in filled epoxy resin.

circuit forces. Moreover, it is difficult to produce to accurate limits. All these troubles are overcome by epoxy cast bushings which are moisture resistant, non-tracking, mechanically robust and can be produced with high accuracy. While not as cheap as a comparable porcelain bushing, epoxy bushings compare favourably in price with S.R.B.P. bushings. Bushings may be cast without vacuum if they are of simple shape.

Among the many other successful uses of cast epoxy resins in the electric industry are slip-ring and commutator insulation, and many types of switchgear insulation.

Cold- or warm-curing epoxy casting resins are used mainly for potting, casting and sealing smaller components and assemblies, such as those encountered in the electronics industry, where they are thoroughly established and are essential when full tropicalisation is specified.

These resins are used in a similar manner to the hot-cured products which find their main use in the heavy electrical industry. Although these lower-temperature curing systems can be used with or without vacuum, depending on the application, it should also be mentioned that vibrating methods have successfully been used for mixing and casting processes.

It is possible to add reactive plasticisers to certain epoxy systems to produce cured products with a degree of resilience. Colouring pastes are also available in the form of pigments and dyes which are carefully dispersed in a small quantity of liquid epoxy resin to facilitate mixing into the base resin.

Tooling Applications

In industry to-day there is a big call for reference tools —in which stability and accuracy are the main requirements—and for press tools which can be made quickly and cheaply and can stand up to short or moderate runs. This call is being met on an ever increasing scale by plastics materials, and in this field epoxy resins offer remarkable advantages.

Epoxy resins succeed as tooling materials because the tools can be produced quickly to a high degree of accuracy directly from simple models, or moulds made from wood, metal or plaster. Curing takes place with negligible shrinkage and can be as low as one thou./ft. The cured products have excellent strength, good dimensional stability, and high resistance to wear. The tools are lighter than those made from conventional tooling materials. The excellent adhesion of the epoxy resins means that they bond well to fillers, and these can be used without detriment to the tool, and indeed often with great advantage. Fillers in powder form or such fibrous materials as glass in the form of rovings or woven cloth or tape impart such properties as resistance to wear, greater impact and tensile strengths. The resins can also be bonded strongly to various core materials such as concrete or metal, and metals can be incorporated in a tool at points where it will be subject to high stresses. Further advantages are that, in the event of a change of design after the tool has been made, modifications can readily be made, high curing temperatures are not required, colours can be incorporated so that tools can be readily identified, and there is hardly any limit to the size of epoxy tools.

The finished casting (or laminate) reproduces the surface of the mould with great fidelity, and, if the mould itself has a good surface, finishing processes are quite unnecessary. If for any reason grinding or polishing is needed, this can be done more speedily and cheaply than with metal.

Epoxy resin tool surfaces are completely resistant to ordinary atmospheric conditions and to corrosion by chemicals and solvents likely to be encountered in tooling processes.

Epoxy resin systems for tooling are available in many forms. They can be made with rock-like hardness, or with rubbery resilience, and any intermediate quality can be obtained.

For making press tools from epoxy resins, casting techniques are invariably used, one component—usually the die—being cast against the pattern. The second component is then made from the first with due allowance for the thickness of the article being made. It is usual to employ two different mixtures, a specially formulated facing mix and a heavily filled low-cost backing mixture.

Drop-hammer dies can be constructed in a number of different ways using epoxy resins. The whole tool can be made from the resin—both core and working face consisting of filled resin mixtures. Alternatively the core can be of lead, zinc or alloy with a special facing based on an epoxy resin. This has the advantage that the core can be recovered when the tool has completed its run.

The methods used in construction are very similar to those used for press tools, the main difference being the use of resilient, and semi-resilient facing mixes and semi-resilient cores.

The forming of deeply drawn components with small

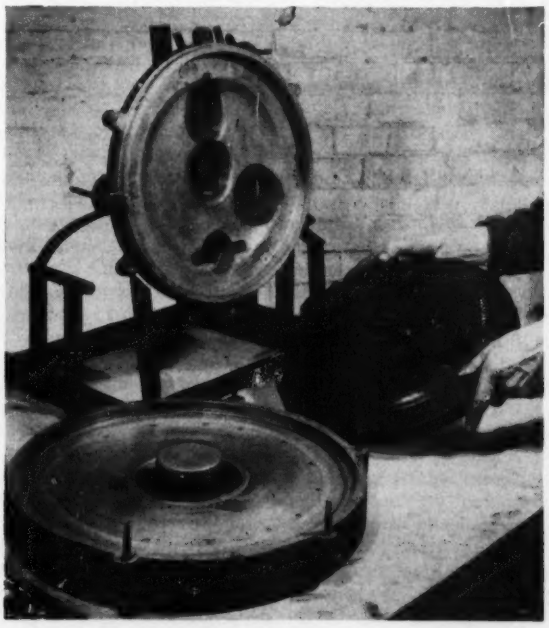
radii generally calls for the use of matched tools. However, where the component is not too deeply drawn, it can often be made in a rubber press, i.e., between a rigid member—generally male-sectioned—and a resilient one.

Specially-filled epoxy resins are ideal materials for the rigid member of rubber press tools and intensifiers. The conventional materials used for rubber press tools are zinc and lead, which are customarily cast, or densified wood, which is machined to the required shape and hand-finished. The advantages of epoxy resin tools, when compared with those based on the other materials, are as follows: They are considerably cheaper than zinc or lead and, since the resins can be cast at low temperature, they are less exacting with regard to the material of the mould. Carefully designed epoxy resin tools wear better than those made of conventional materials. In places where stresses may be exceptionally high, glass fibre reinforcement can be readily incorporated.

A stretch block is a die, normally of male section, over which a blank of sheet metal is formed by pulling until the shape of the block is reproduced in the blank. A popular technique employs concrete cores with working faces based on epoxy resins. A significant advantage arising from the use of these resins is that scoring and scratching of panels, normally associated with concrete stretch blocks is eliminated.

In the manufacture of tools for the vacuum forming of thermoplastic sheet, good thermal conductivity is obtained by adding a metallic powder filler—generally aluminium—to the resin. Thin or prominent sections of a cast epoxy resin vacuum-forming tool may be reinforced with glass fibre. The vacuum holes may be made by drilling in the finished casting or, alternatively, time may be saved by inserting well-greased needles in the mould in appropriate positions. The needles are withdrawn after curing. If desired, it is a comparatively simple matter to incorporate cooling tubes, preferably copper, in the casting.

Epoxy casting resins also find a wide and rapidly growing use in the manufacture of foundry patterns. The technique for casting patterns consists first of making a mould of plaster or plastic stone from the original wooden or metal pattern. Alternatively, the mould may be made of low melting-point alloy, applied to the pattern by means of a spray gun or of clay-bearing sand surface hardened with a urea-formaldehyde resin.



Epoxy cast resin part of the "Agglometron", developed by Menrow Ltd., being removed from a metal mould.

Typical properties of unfilled epoxy casting resins.

Data is given purely as a guide. Properties vary with different resin hardener systems.

Heat Distortion Temperature (°C.)	55–160
Specific Gravity	1·2–1·3
Flexural Strength (1,000 p.s.i.)	12–20
Tensile Strength (1,000 p.s.i.)	5–12
Compressive strength (1,000 p.s.i.)	12–18
Modulus of Elasticity (10^6 p.s.i.)	0·28–0·58
Coefficient of linear expansion ($\times 10^{-6}$/°C.)	60–90
% water absorption. 10 days at 20°C.	0·25–0·5
1 hour at 100°C.	0·3–0·7
Thermal conductivity cal./sec./cm.²/°C./cm. $\times 10^{-4}$	4·7
BTU/sec./ft.²/°F./in. $\times 10^{-4}$	3·8
Dielectric constant 10^3cs. at 20°C.	2·8–4·0
Power factor (tan) 10^3cs. at 20°C.	0·006–0·019
Dielectric strength (volts/mil, short time, ¼in. section)	400–500

A mixture of epoxy casting resin, hardener with suitable inorganic filler such as marble flour is then poured into the mould and allowed to cure usually at room temperature for 24 hours. If speed is of importance, the casting can be allowed to gel at room temperature and then post-cured at an elevated temperature.

Other Applications

Because of their outstanding chemical resistance and dimensional stability, certain epoxy casting resin systems are finding growing application in the chemical engineering industry. Valves, pipes, spray nozzles, taps and many other structural parts have been successfully produced. The resins have been used both with and without fillers.

Among applications for epoxy casting resins not yet described may be mentioned their use as models for research into stress distribution by photoelastic investigations or by expansion measurements.

Two experimental methods are often employed with epoxy casting resin models. In one, loaded models in clear resin are studied or photographed in polarised light to give details of the direction and magnitude of the stresses. In the other method the expansion of the model under known loading is measured. By calculation from the modulus of elasticity of the model materials the stresses at a given point can be obtained. Strain gauges or tensometers are used to measure the changes in the model which can be made from an epoxy casting resin.

Latterly they are finding use as embedding media for electron microscopy. The first trials of epoxy resins for this purpose were made by Maaløe and Birch-Anderson in 1956. Other workers, notably Audrey M. & Dr. R. H. Glauert, have described successful results with special epoxy casting resin mixtures. Advantages of the epoxies include virtually no shrinkage on curing and, unlike methacrylate, the hardened epoxy resin is not degraded by the electron bombardment.

Containers made from epoxy resins are capable of operating under very high vacuum conditions, i.e., down to 10^{-8}mm. Hg. and because of their high hydrogen content are successful neutron absorbers. They are being used as adhesives at −180 deg. C. and as laminates at +250 deg. C.

The use of epoxy casting resins within the engineering industries is already well established and with continual chemical research and application development their field use is expanding rapidly. As the engineering industry becomes increasingly aware of the successful results that can be obtained by designing around their unique combination of properties their future is assured.

STAINLESS STEEL AS A STRUCTURAL MATERIAL

Stainless steels are used increasingly in every field of engineering. In this first of two articles, specific problems associated with the properties of certain stainless steels are examined

by I. L. G. BAILLIE, B.Sc., A.M.I.Mech.E.*

THERE is increasing interest in the potential use of high strength steel sheet materials for major structures as a competitor to aluminium, titanium or nickel alloys. The purpose of this article is to provide a brief survey of the properties of some of these steels, and to indicate the types of application for which they may prove suitable; although the results discussed below have been obtained during investigations connected with airframe development, the potentiality of these steel sheets would not appear to be restricted to that application alone.

For the high strength steel sheets it is not, in general, possible at present to obtain all the information required, and some further development work may need to be initiated to demonstrate suitability for the intended application. However, the potential advantage to be gained by using one of these steel materials may well outweigh this extra effort. In this article the characteristics of four high strength steel sheet materials will be discussed, and it is hoped that this will provide a basis for judging whether such materials could solve a problem in material selection.

TYPES OF HIGH STRENGTH STEELS AVAILABLE IN SHEET FORM—Metallic materials can be divided broadly into two classes: (a) the heat-treatable class where the strength is obtained almost wholly from the heat treatment sequence and (b), the cold-workable class where the strength is obtained from plastic deformation (e.g., cold rolling) during production. Development of steels recently has been mainly in those with good inherent corrosion resistance, and this article will deal only with such steels, and the four steels chosen for description are summarised in Table 1. The steels described are all supplied by Firth-Vickers (Stainless Steels) Ltd.; this is purely a matter of convenience and a function of availability of data to the author, and it is to be noted that other suppliers also have ranges of production or experimental steels of these types as well as many others.

The following notation is used:

E	Young's Modulus	10^3 p.s.i.
c_1	0.1 per cent Compression Proof Strength	tons/in^2
t_1	0.1 per cent Tension Proof Strength	tons/in^2
f_t	Ultimate Tensile Strength	tons/in^2
e	Elongation	%

MARTENSITIC STEEL: FV.448: MAJOR CHARACTERISTICS—Although the basic 12 per cent Cr type steels show reasonable strengths, additional alloying elements in a carefully controlled composition provide in FV.448 a steel with particularly good creep-resisting properties at temperatures around 550-600 deg. C., and FV.448 was initially developed for aero-engine applications. However, it is also stronger than other Cr steels and in particular it shows higher E value than any other steel; it is therefore of major importance for compression structures where collapsing strength is primarily a function of E.

HEAT TREATMENT: SELECTION OF TEMPERING TEMPERATURE—As FV.448 is a hardening and tempering steel, the mechanical properties are adjustable within a wide range according to the designer's requirements. Tempering curves show that there are three conditions in which the steel is of particular interest:

(a) Softened around 750 deg. C. when strength is not high and forming is therefore relatively good
(b) Tempered around 650 deg. C. when strength is higher and the creep properties at 550 deg. C.-600 deg. C. can be utilised
(c) Tempered around 550 deg. C. when the highest strength is obtained.

Tempering for High Strength

It is FV.448 in condition (c) which will now be discussed as this is the condition of major interest for structural purposes. FV.448 has to be tempered within a carefully selected and controlled range if the best properties are to be achieved, and this range is governed by these factors:

(i) As the tempering temperature increases towards 600 deg. C. a preferential precipitation of carbides occurs at grain boundaries, the effect being more marked with longer tempering times. If this preferential precipitation occurs then strengths consistently over 70 tons/in^2 cannot be achieved, and it is normally considered desirable to reduce the tempering temperatures and time sufficiently to overcome this
(ii) As the tempering temperature decreases towards 500 deg. C. the strength increases to 85 tons/in^2 or more, and the stress corrosion characteristics deteriorate quickly in accelerated conditions.

Compromising between preferential grain boundary precipitation on the one hand and poor stress corrosion properties on the other, a tempering range of 540 deg.-560 deg. C. for 1 hour seems to give a very satisfactory steel (only 3 temperings are advisable without rehardening). This 540 deg.-560 deg. C. range follows hardening at 1000 deg.-1020 deg. C. for 30 mins. and air cooling to ambient temperature; if the hardening temperature is altered, the best tempering range may require modification.

HEAT TREATMENT TO ACHIEVE HIGHEST STIFFNESS—If

* *Chief materials and processes engineer, Bristol Aircraft Ltd.*

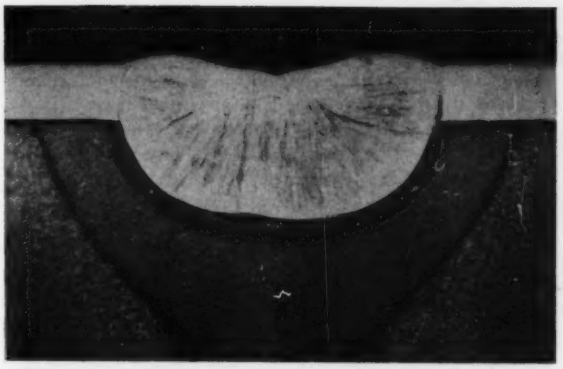


Fig. 1. Cross-section of a typical "puddle weld", joining 0·064 in. FV.FDP (at top) to 0·264 in. FV.448. Magnification: x 10. Etch: acid ferric chloride. Sharp line of demarcation between weld pool and parent material does not indicate inadequate fusion; it is merely a secondary effect from using a deep etch to accentuate the microstructure and occurs irrespective of the welding method.

the stiffness of FV.448 is not critical, no heat treatment subsequent to tempering will be needed. However, if stiffness is of major importance it is necessary to eliminate the drop in E caused by flattening and/or forming operations. It has been found that heating for around 2 hours in the range 450 deg.-530 deg. C. both improves the E and removes any drop produced by cold work; it appears to provide a form of stress relief. 500 deg. C. may prove convenient in plant where solutionising of aluminium alloys is a standard process.

Depending on the rejection rates which are regarded as acceptable, inspectional control for modulus can be applied to FV.448 to guarantee compression E values of 30 or even 31×10^6 p.s.i. If sheets require significant curvature or cold work then this 500 deg. C. treatment must follow forming; if the forming is very mild, however, it may safely follow the 500 deg. C. treatment. The latter procedure is much less inconvenient in production as

(a) small dimensional changes will occur and some distortion can be expected;
(b) unless a neutral atmosphere is used, a thin scale will be formed, visible as a temper colour. It will generally be desirable to remove this mechanically or chemically, particularly if the material is to be subsequently welded.

FLATNESS OF SHEETS AS MANUFACTURED—FV.448 sheets are individually rolled and the major single difficulty associated with these sheets is their lack of flatness. If sheets are hardened and tempered to the 70 ton/in² min. strength condition without special support, then the final sheet will be bowed and wrinkled, and quite unacceptable for subsequent operations. Conventional techniques, although suitable for FV.448 at the lower strength ranges, are inadequate for flattening sheets in the strong condition; special techniques are therefore employed by the material manufacturers, as follows:

(a) For thick sheet (say 0.15 in. or 0.20 in. up to 0.40 in. or 0.50 in.) special quenching supports, followed by hammering (smith flattening), are required; this involves individual handling of each sheet and is obviously laborious.
(b) For thin sheet (say around 0.08 in. to about 0.15 in.) the hammering procedure is ineffective; sheets are stretched prior to hardening and suspended vertically during hardening. This still means individual handling of each sheet, but the general procedure is less onerous.

SURFACE FINISH OF SHEETS AS MANUFACTURED—During softening operations between the various hot-rolling reduction stages there is some scaling; this scale is not easy to remove and some tends to be retained and rolled into the surface in subsequent reduction. In final heat treatment there is further scaling, and the subsequent descaling tends to leave a rough surface with depressions at locations where rolled-in scale has been removed.

MACHINING OF SHEET TO PRODUCE THE FINAL THICKNESS—The poor surface finish combined with the lack of flatness means that FV.448 in the high strength condition is not, when received from the supplier, immediately usable for engineering structures. It has to be regarded as machining stock, and the user will need to arrange for both surfaces to be machined to provide:

(a) An acceptable surface finish (which may mean grinding),
(b) Acceptable thickness tolerances, and
(c) Acceptable flatness.

FORMING AND ASSEMBLY OF SHEETS—Provided a flat sheet is required, then stiff assembly jigs, with loading devices, such as hydraulic jacks, will be adequate to handle machined sheets. If the final sheet is required to be curved, then a similar approach will suffice provided the curvature is so mild that the free sheet could naturally deform or "droop" into the required form largely under its own weight.

However, if the required shape is not so simple or if it

TABLE 1—Steels described in this article

Type of Steel	Principal alloying elements	Strength obtained by	Firth-Vickers Code No.
Martensitic	12% Cr + (Mn, Mo, V, Nb)	Hardening and tempering	FV.448
Austenitic (Stabilised)	18% Cr 8% Ni + (Ti or Nb)	Cold rolling	FV.FDP
Austenitic	17% Cr 4% Ni 6% Mn	Cold rolling	FV.FSM.1
Quasi-Martensitic	17% Cr 5% Ni 2% Cu 2% Mo	Precipitation hardening	FV.520

TABLE 2—Comparison of strip rolling with sheet rolling for FV.FDP

Advantages	Disadvantages
1. Highest strength (with corresponding loss of elongation).	1. Outcropping Ti stringers give longitudinal defects instead of 'shell' markings.
2. No length limitations for widths up to 40 in.	2. Stretch forming not possible.
3. Closer thickness tolerances for widths up to 36 in. (i.e., 2 in. edge trimming).	3. Minimum quantity supplied normally 9,000 lb.; initial test evaluation therefore hindered unless offcuts available.
4. Superior flatness standard.	

TABLE 3—Modulus Values for FV.FDP

Condition	Loading	Test direction	Modulus: 10^6 p.s.i.	
			Sheet rolled	Strip rolled
As Rolled	Compression	Long. Trans.	24 /25½ 28 /31	24½/26 27½/29½
	Tension	Long. Trans.	24 /25½ 27½/29½	25 /26 27½/30
After heat treatment at 450°/550° C.	Compression	Long. Trans.	27 /29 30½/32½	27 /28 29½/30½
	Tension	Long. Trans.	26½/28 28 /31½	26½/28 28½/30

involves any significant double curvature then FV.448 is too strong and too stiff to be considered, as no techniques are known which would enable such shapes to be produced. The proof/ultimate ratio is high, and stretching is impossible cold; it is also impossible at around 500 deg. C., as the first slip line to occur does not work-harden and therefore simply necks to fracture. Wheeling and rolling techniques seem impossible also, due to loads required.

MECHANICAL PROPERTIES—In the 70 ton/in² min. strength condition, FV.448 shows a high proof strength and elongations around 10 per cent. Provided local preferential carbide precipitation has been avoided these properties are very uniform over a sheet. The properties in the longitudinal and transverse directions are very similar; properties in tension and compression are also very similar, although the compression E tends to be a little higher than the tension E. Straining rates during testing do not seem to be important.

Having been developed originally for creep resistance at elevated temperatures, FV.448 shows good elevated temperature properties.

WELDING PROPERTIES—In the low and medium strength range conditions, FV.448 can, with care and proper control, be welded in continuous runs. In the 70 ton/in² min. strength condition, however, welding by normal methods is not possible; it is possible to tack weld a material such as FV.FDP to FV.448 but not even to tack weld through FV.448 to itself or any other material. A typical tack weld of FV.FDP to FV.448 is shown in fig. 1: this weld was produced by the "puddle welding" process which uses a tungsten electrode but no welding pressure; such welds have been found to have good shear and tensile static strengths and reasonable fatigue characteristics, but a reduction in the carbon content of the FV.448 from 0.14 per cent. to 0.10 per cent. max. is advisable to reduce peak hardening.

CORROSION PROPERTIES—FV.448 is not a fully stainless steel, as in time it forms a rust film. This film, however, appears to seal the surface and not to be associated with any corrosion pits or stringers which could act as failure nuclei. Some form of protection scheme may be desirable, depending on the application, but from purely structural considerations does not seem to be essential in normal atmospheres. If the surface is accessible, waxing and polishing will provide a good treatment.

Stress-corrosion characteristics have already been discussed for FV.448 in connection with selection of tempering temperatures and times.

SUMMARY OF POTENTIALITIES OF FV.448—FV.448 can probably be regarded only as a plate material requiring machining; it does not rust seriously, but is available to reasonable flatness standards only as individual sheets. If the shape of the final component allows fabrication, FV.448 will provide a very high E for use in design, and therefore offers optimum weight for a highly loaded compression structure. One incidental advantage is that FV.448 is also a bar material so that forgings, machined fittings, bolts and even rivets can be of common composition.

AUSTENITIC (STABILISED) STEEL : FV.FDP: MAJOR CHARACTERISTICS—Steels of the 18/8 Cr.Ni type have for some time been widely used for many purposes. They are stainless and (provided they are "stabilised") are suitable for welding by most conventional processes; they can be used either in the annealed condition when formability is excellent or in the cold rolled condition when high strength is required but, for high strength application, care is required at the design stage as they exhibit some unusual properties.

METHODS OF MANUFACTURE—FV.FDP is produced by hot rolling followed by cold rolling with intermediate softenings. The cold rolling can either be on individual sheets or on a continuous strip mill. As the characteristics of material produced by these two methods are different, it is necessary to specify the manufacturing technique when considering the material. The main advantages of strip rolling relative to sheet rolling are shown in table 2. Strip rolled material is capable of tighter strength and dimensional control, and for the more severe applications this form is preferable.

MECHANICAL PROPERTIES AS MANUFACTURED—In the cold rolled condition, all 18/8 Cr.Ni steels show marked non-uniformity of mechanical properties:

(a) Directional variations are very marked and unlike most engineering materials it is the longitudinal direction which is the weaker (see fig. 2). Tension and compression moduli (see table 3) and compression proof strength are the properties worst affected, and design must take the variations into account. As the directional variation is a function of the directional cold rolling, it is even more marked in strip rolled material than in sheet rolled

(b) In addition to the directional variations there are also differences between tension and compression properties (see fig. 3). These differences are most marked in longitudinal proof strengths where the compression strength is markedly lower than the tension strength; this effect also needs to be accommodated in design.

Fatigue data on un-notched specimens have shown that for 10^5 cycles the ratio of fatigue strength to static strength is a little over 0.50; this is encouraging. As FV.FDP is a

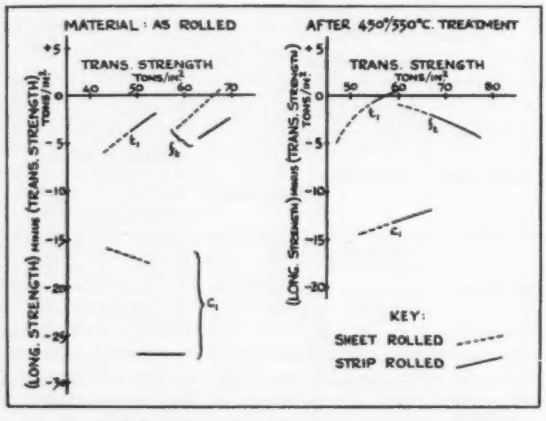


Fig. 2. Directional strength variations in FV.FDP before and after heat treatment.

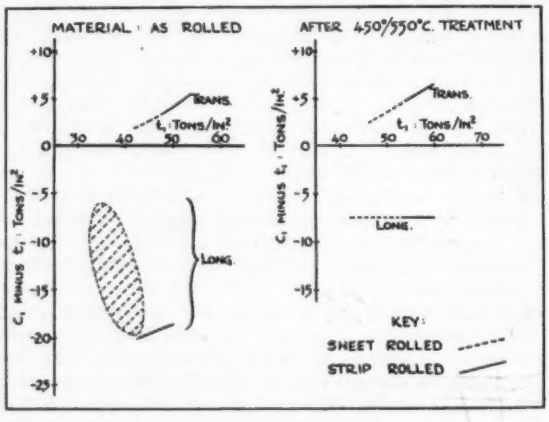


Fig. 3. Variation of c_1 with t_1 in FV.FDP before and after heat treatment.

cold-worked material its properties at elevated temperatures drop more quickly than do those of FV.448.

In the softened condition FV.FDP shows E values of around 27×10^6 p.s.i., which is low compared to the E of FV.448. Moreover, only a small amount of cold work is sufficient to reduce the E of FV.FDP to around 24×10^5 p.s.i., so that in the high strength conditions FV.FDP has an E some 20 per cent. lower than FV.448.

HEAT TREATMENT TO IMPROVE E AND PRESTRAIN EFFECTS—The undesirably low E of FV.FDP in the stronger conditions can be virtually returned to the level of E in the softened state (see table 3) by a heat treatment at about 450 deg. C. for 2 hours or at about 525 deg. C. or 550 deg. C. for 4 hours; as with FV.448 the treatment can be regarded as a stress relief. After treatment inspectional control can be provided to give guaranteed E values of around 27×10^6 p.s.i. if required.

The temperature to be used should avoid the 500 deg. C. range as this appears to produce a condition of minimum ductility; an upper limit exists around 590 deg. C. when softening commences, whereas much below 450 deg. C. it is believed that adequate improvement in E would not occur. The 450 deg. C. treatment may tend to give slightly greater strength and poorer ductility than the 525 deg. or 550 deg. C. treatments but the difference in effects is not marked. All the treatments tend to give some improvement in proof and ultimate strengths (see fig. 4), but more important than this is their effectiveness in largely eliminating any drops in compression proof strength due to tension prestrain (as would occur during forming). After treatment the directional variations in properties are much reduced although they are still significant, and the differences between tension and compression properties have also been reduced.

CORROSION PROPERTIES—FV.FDP is a corrosion-resisting material having a good finish, subject to attack from only a very limited range of media. However, during the 450 deg. C. or 525 deg./550 deg. C. treatment a scale is formed and, if this scale is not removed, damaging corrosion will occur without specific activation, apparently due to galvanic action between the scale and the parent material and to the inability of the parent metal to form a protective seal in this state. Chemical or mechanical removal of the scale is necessary as soon as possible after heat treatment, and the material again becomes fully stainless.

WELDING PROPERTIES—FV.FDP is weldable by most welding processes, being stabilised by the Ti or Nb addition against weld decay, but the weld zone will be fully soft, any cold work effects being removed by the heat. Processes such as spot or "puddle" welding (mentioned under FV.448) are therefore preferable to continuous welding. When FV.FDP is to be welded after heat treatment the heat treatment scale must be removed before welding.

FORMING AND ASSEMBLY OF SHEETS—FV.FDP shows good ductility for its strength, but this is by itself insufficient to guarantee satisfactory stretch-forming characteristics. The shape of the full stress-strain curve is also of major importance, and if this curve is flat-topped (see fig. 5) then the higher stressed (i.e., the tauter) portions will stretch to failure before the lower stressed (i.e., the slacker) portions have been adequately stretched. In the higher strength conditions over about 50 tons/in² strip rolled material always gives flat topped curves and sheet rolled material sometimes does also. Stretch forming of FV.FDP is therefore only possible for some sheet-rolled batches.

However, severe single curvatures can be produced by rolling or wheeling, and a degree of double curvature can be induced by local wheeling so that complex shapes can be formed at least in thinner sheets. When rolling it is advisable to use special rolls or to sandwich the FV.FDP between soft material to avoid the sheet edges marking the rolls. Such marks would not prevent the rolls being used for further work on FV.FDP but would imprint softer materials such as aluminium alloys.

Bend radii can be formed satisfactorily in FV.FDP down to 3t or 2½t, but 2t may not be achieved consistently. Special tools are advisable for producing good geometry at bends, and periodic trouble with surface Ti stringer marks causing cracking at bends must be expected if strip rolled material is used.

SUMMARY OF POTENTIALITIES OF FV.FDP—FV.FDP is not as efficient as FV.448 for compression structures or other applications requiring high stiffness. However it is available as continuous strip to close tolerances, and can be formed to quite severe shapes; it is therefore a possible choice where FV.448 is impractical. Heat treatment of FV.FDP after forming seems very desirable to reduce or eliminate some of the unpleasant strength features which occur in the cold rolled state.

By comparing the types of structure for which FV.448 and FV.FDP are most suitable, it will be seen that one or the other could be used for a wide range of components and that welding could be employed for many joints. It is, however, clear that the difficulties in using these materials would be considerable and that improved materials are needed. In part 2 of this article two further steels, FV.FSM.1 and FV.520, will be described; they are from several points of view more attractive for design and production, and indicate the improvements being made in the field of high-strength stainless steel sheet to meet the designers' needs.

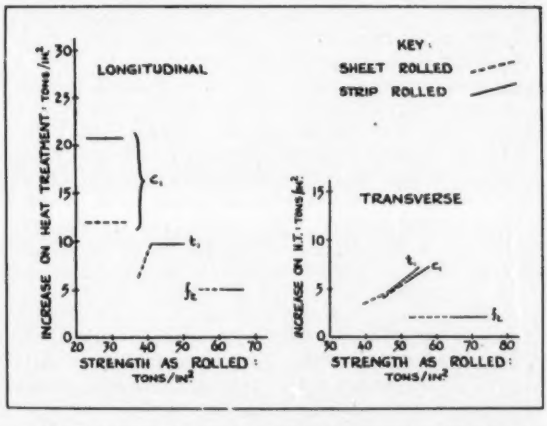


Fig. 4. Increase in strength of FV.FDP due to 450/550 deg. C. heat treatment.

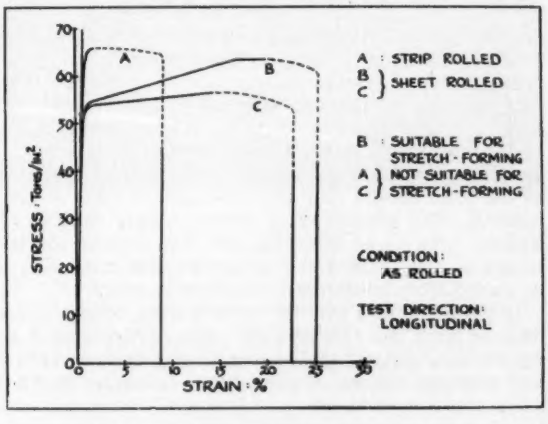


Fig. 5. Complete stress-strain curves: FV.FDP.

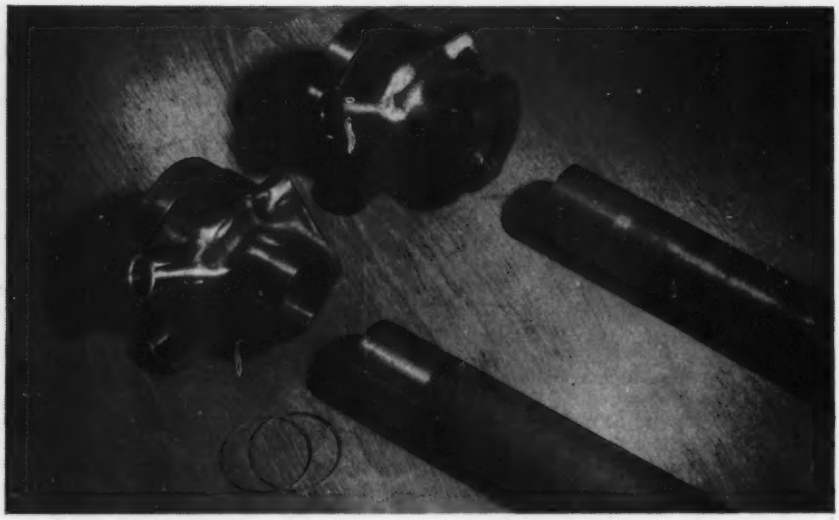


Fig. 1. A.E.C. steering column sub-assembly showing (above) method formerly used, and (below) the redesigned assembly ready for silver brazing.

DESIGN FACTORS IN SILVER BRAZING

Silver brazing can offer many advantages to the designer. This article outlines the ways in which the process can be exploited and emphasises the need to design specifically if its best features are to be achieved.

L. D. CONNELL, [illegible]

SILVER brazing has become widely accepted as a versatile production method for the joining of metal components, and this method can offer many advantages if the decision to employ it is taken at the design stage. Provided that the designer is fully conversant with fundamental silver brazing principles, he is able to include certain simple features in the design of components that will greatly facilitate the brazing operation, resulting in sound high-strength joints together with reduced production costs.

The position gained by silver brazing in mass production assembly may be attributed largely to the low temperatures involved, thus shortening the heating stage, which results in time saving. Where sheet components are concerned, low brazing temperatures lead to less distortion, which will usually mean a reduced treatment in later assembly. Further economy is achieved in finishing for the neat fillet formed around the joint often requires no dressing.

A common failing when silver brazing techniques are first introduced to manufacturing processes is the attempt to use joint designs that are applicable to other jointing methods. The adaptation of designs ideally suitable for welding, riveting or threading does not produce the best results or fully exploit the advantages and economies to be gained from low-temperature silver brazing.

In the design of a joint for silver brazing, several factors must be taken into consideration: joint requirements, heating method, type and applications of brazing alloy material and proposed volume of production. The order in which these factors are considered is not critical, but it is of fundamental importance that all should be given due thought in order to determine the most effective type of assembly and the most efficient brazing technique to be employed.

The real strength of a silver-brazed joint arises from the shear component. The design should ensure that the main area of joint is in the same plane as the direction of the stress to be applied and is large enough to produce the required strength. Where non-ferrous components are to be jointed, a general guide is that if the shear area of the joint is three times the cross sectional area of the thinner member, then over-stressing will result in fracture of the member rather than fracture at the joint.

Where high fatigue strength is of fundamental importance, silver brazing offers considerable advantages because of the relatively large area joined in brazing compared with the joint area employed in welding or riveting. The ratio of the area of shear to the area of cross section may have to be made considerably larger than three to one where high fatigue strength is critical. Normal fatigue rules, as applied in other joining methods, must be observed, the joint being formed away from any abrupt change in section. Where jointing near an abrupt change of section cannot be avoided, a larger concave fillet in the silver brazing operation will prevent stress concentrations.

HEATING METHODS—There are five basic ways in which heat can be applied in the silver brazing process, varying from hand to semi-automatic and fully-automatic methods, and the choice will depend largely on the volume of production.

* *Johnson, Matthey & Co. Ltd.*

By far the oldest heating method, the hand torch, is still widely used for low-volume production and even for high-volume production where the assembly to be brazed is of a simple nature. Usually compressed air/coal-gas or oxy-acetylene is employed, the former producing a softer flame with less chance of burning the metal. Where oxy-aceylene is used it is often difficult to prevent operators from employing welding techniques, which, when applied to silver-brazing operations, result in burning or over-heating. However, in the hands of a competent operator torch heating can produce excellent results.

Fixed torch equipment represents an advance on the hand torch as in this heating system gas and air are pre-mixed and fed to specially located burners. These burners are designed to present to the work piece a number of small flames which do not splash, and as a result, increased heating rates and greater depths of heating are possible. The torches are pre-placed relative to the work so that the required heat pattern is obtained, while the correct time cycle can be ascertained and controlled by electrical or mechanical devices. The assembly may be completed by the addition of a turntable or some similar equipment.

In recent years induction heating has become increasingly popular. In this method eddy currents are induced by passing a high frequency current through a water-cooled coil placed around the assembly, thus generating heat in the assembly. The amount of heat is dependent on the square of the induced current and on the resistance of the material, a high-resistance material tending to heat more rapidly than a low-resistance material. Though this heating method is frequently applied to non-ferrous materials, it is most widely employed for ferro-magnetic alloys, in which additional heating results from magnetic hystersis.

Resistance heating finds useful application in the brazing of small joints or where heating has to be localised. The passage of electric current through graphite electrodes, which are in contact with the work, causes them to glow red hot and heat the assembly by conduction. With this method extremely rapid rates of heating are possible.

Furnace brazing, where reducing atmospheres are employed, can at first sight offer significant advantages since a flux is unnecessary and no pickling operation is required after brazing.

However, a problem arises through the fact that it is almost impossible to prevent the ingress of water vapour, either because of inadequate drying of the gas or because of entry of the ambient atmosphere. For this reason furnace heating using silver brazing alloys has never achieved wide popularity, for a furnace atmosphere having a dew point of −20 deg. C. is required if reliable results are to be obtained without using flux.

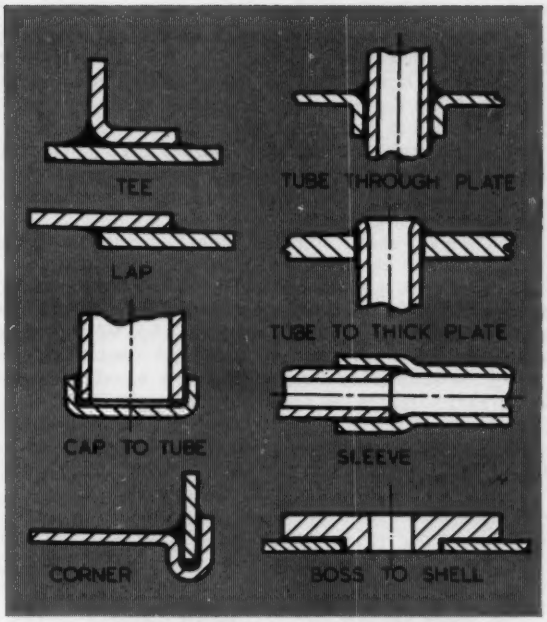


Fig. 2. Ideal joint designs for silver brazing.

Application of the Brazing Alloy—The mechanics of liquid metal flow must be fully understood when considering the application of the brazing alloy. Capillary attraction is the major factor in penetration and although in theory a penetration of several feet is possible with correct design, in practice the extent of capillary penetration is dependent on the dimensions of the joint. The best results are obtained where a joint gap of 0.002-0.004 in. is employed. If the optimum joint gap is to be maintained during the heating cycle, allowance must be made for the different expansion coefficients of the component metals used in the assembly.

When the assembly is at the same temperature as the brazing alloy, capillary force is the major factor, but molten brazing alloy is always attracted towards regions of higher temperature. If the joint is designed so that the temperature gradient works against the desired direction of capillary flow, then a successful joint will not be achieved. Careful design and good operating technique will ensure that the applied heat will travel through the joint to the brazing alloy, helping the capillary force to draw the molten alloy through the joint and flush out any flux.

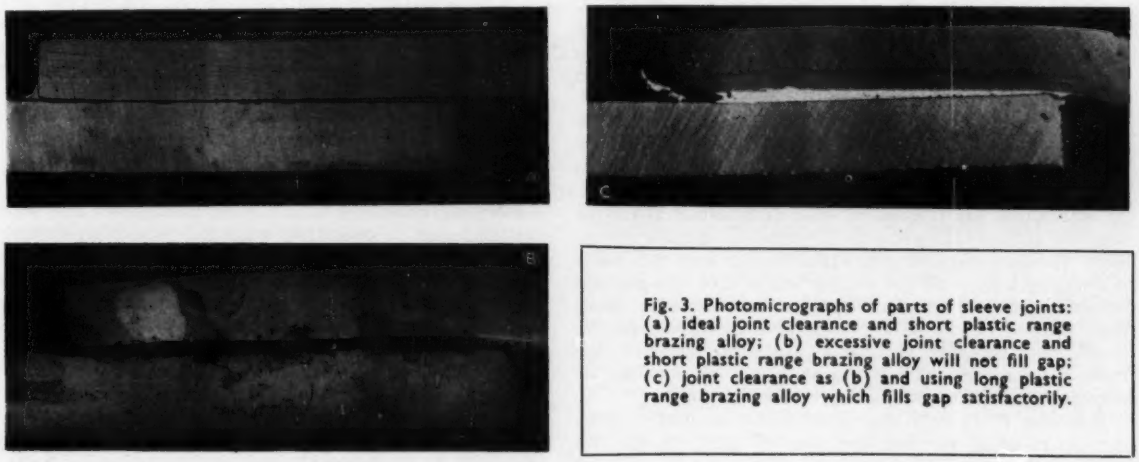


Fig. 3. Photomicrographs of parts of sleeve joints: (a) ideal joint clearance and short plastic range brazing alloy; (b) excessive joint clearance and short plastic range brazing alloy will not fill gap; (c) joint clearance as (b) and using long plastic range brazing alloy which fills gap satisfactorily.

In nearly every assembly the volume of the brazing alloy will be relatively small; as a result, its thermal capacity will be low and it will tend to reach brazing temperature rapidly. If the flame impinges directly on the brazing alloy it will melt and run off or else form an unmanageable globule long before the joint has reached brazing temperature. The assembly should so be arranged that the brazing alloy is heated by conduction from the component and not directly by the flame.

The actual volume of brazing alloy to be used should be ascertained by utilising the top-tolerance joint clearance, which will give the maximum possible cross sectional area of the joint, and to the calculated volume, 25 per cent must be added to allow for the production of a suitable fillet. The result can only be regarded as theoretical, providing the foundation for practical tests on which actual requirements should be based.

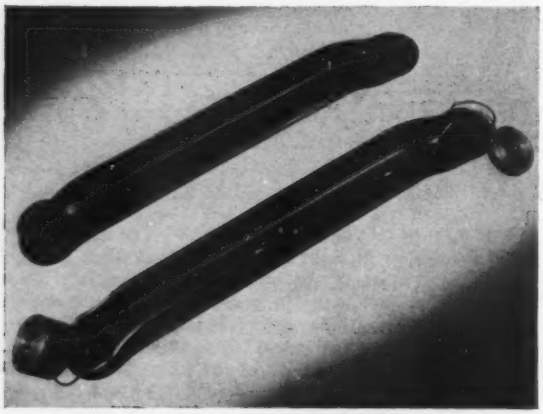


Fig. 4. Lower linkage of Sunbeam Rapier front suspension before and after brazing operations.

Volume of Production

It must be appreciated that the volume of production required will largely determine the type of process to be used. Where high volume is required, induction, resistance or furnace brazing methods can be considered, and for lower production volumes, fixed or hand torch brazing will be sufficient. It is impracticable to give general recommendations on this point, for the complexity of the assembly and the nature of the material to be brazed will greatly affect the speed of operations and the choice of process.

The cost of installing and running each process differs widely, but generally the most expensive is induction heating, followed in order by fixed torch and resistance heating, with the hand torch the most economical method. The cost variations in the employment of furnace brazing are so wide that it is difficult to place in the order of cost.

CHOICE OF BRAZING ALLOYS—Ideal requirements for joint tolerances and assembly methods often cannot be economically reached or maintained. Though the ideal joint gap is 0.002-0.004 in., where sheet metal is involved, or where, for the reasons of cost, commercial standards must be applied, adherence to the ideal is virtually impossible. The only solution to this problem lies with the choice of brazing alloy. Silver brazing alloys can be grouped roughly into two classes, the essential difference being their melting ranges. Where ideal joint clearances can be maintained, the most successful results together with the most economic use of brazing alloy will be obtained by employing an alloy with a short melting range.

However, if the joint gap varies from the ideal—and is, say, up to 0.008 in.—this first class of alloy, though still usable, will not produce the best results, and an alloy of longer plastic range that will satisfactorily fill the wide joint gap should be employed. However, this second class of alloy does not possess the same powers of penetration. Characteristic examples of these two classes of alloys are shown in Table 1.

TABLE I. Silver brazing materials

	Easy-flo No. 2* (Short plastic range)	Argo-flo* (Long plastic range)
Melting range, °C.	608-617	605-651
Tensile strength, p.s.i.	67,200	71,680
Shear strength, p.s.i.	24,640	24,640
Elongation, %	30	20
Vickers hardness	135	136
Electrical conductivity % I.A.C.S.	20	20

**Products of Johnson, Matthey & Co. Ltd.*

EXAMPLES OF SILVER BRAZING DESIGN—The following are typical examples illustrating the economy achieved by designing components to be assembled by silver brazing, rather than producing in solid form or assembling by other means.

Fig. 1 illustrates an instance where the adaptation of an original design to silver brazing has been highly successful and shows two arrangements for the assembly of the A.E.C. steering column. Formerly the column was assembled by threading and locking, using the components shown on the right of the photograph. This was an expensive production method in terms of machining time to produce the close tolerance threads and in labour required to assemble the machined parts.

The components are now produced to tolerances suitable for brazing avoiding some expensive machining operations as shown in the lower half of the photograph. A wire-ring insert is preplaced in the bored hole and the assembly is brazed by induction heating. Inspection problems after brazing are negligible, for the soundness of the joint can be seen immediately by the presence of a fillet of brazing alloy at the mouth of the joint gap, indicating that the alloy has flushed evenly through the joint.

The lower linkage of the front-suspension assembly of a Sunbeam Rapier is shown in Fig. 4. Bosses have to be joined to the linkage and, though other joining methods are effective, in service the gap left between the boss and the link collects water and the metal corrodes. Resort is made to silver brazing for with this method there is no gap after the joining operation and the brazing alloy itself is resistant to corrosion.

Both the bosses are located in recesses that give maximum strength under shear loading. As the linkage is a pressing and the bosses are cut from commercial bar, close tolerances cannot be held and a brazing alloy with a long plastic range is used, the parts being loaded on a turntable and heated by induction.

NEW BOOK

Inorganic Fibres, by C. Z. Carroll-Porczynski. This book has succeeded in presenting data and interesting applications in a manner which should not fail to interest students, scientists and laymen. It is an outstanding contribution to the knowledge of this subject which is of increasing importance to practically every industry.

There are chapters devoted to glass fibres, textiles and wools, with notes on their history, manufacture, properties and applications, and others dealing with slag and rock wools, refractory fibres, asbestos and wire weave, and finally with metal wools, yarns and metallised fibres. (*National Trade Press*. 57s. 6d.) R.D.C.

NEW COPOLYMER RIVALS H-D POLYETHYLENE

FROM OUR OWN CORRESPONDENT

A THERMOPLASTIC copolymer of ethylene and another monomer (identity undisclosed) has been developed to provide higher strength and better long time load-bearing characteristics than those available in higher density polyethylene. Although a great deal of research interest has been expressed in the U.S. in developing such materials, Celanese Corp. of America is the first to announce such a copolymer as commercially available.

Trade named Fortiflex B, the material is said to be primarily intended for use as monofilament for yarns and rope. Other resin types for use as film, wire coating, pipe, blown containers and paper coatings are planned.

The aim of copolymerisation of other monomers (such as propylene, butene or isobutylene) with ethylene is to add side chains of the proper type at the proper intervals to the long, straight molecules of linear polyethylene. Such controlled quantities of side chains provide better strength characteristics by inhibiting slip between the molecules when the plastic is stressed.

Though limited property data are available, a filament creep test comparing Fortiflex B with high-density polyethylene showed that when stressed with a dead load of about 25 per cent of their tensile strengths, the copolymer fibre elongates less than 10 per cent and does not rupture in 300 hr. The high-density polyethylene fibre displays an elongation of about 50 per cent and ruptures in about 100 hr.

Nylon in Carburetter Cam

The replacement of a low-carbon steel cam by an injection-moulded nylon cam in an automotive carburetter provided Holley Carburetor Co. with a 50 per cent saving in manufacturing costs, by eliminating three production operations (stamping, hardening and assembling) and improved operation of the carburetter by reducing friction and increasing wear resistance.

Located between the choke housing and the main body of the carburetter, the fast-idle cam increases the idle setting when the engine is cold. When the engine reaches normal operating temperature the cam cuts out, reducing idling speed to normal.

Only 1¼ in. in length and weighing less than 1 oz., the nylon cam is injection-moulded by Chicago Molded Products Corp. in a multiple-cavity mould with removable sections. The removable sections permit inexpensive alteration of the mould to produce different-sized cams.

Advanced Spraying Concept

A new coating technique has been developed which can vaporise and spray any known element, or combination of elements, on to a wide variety of base materials. Announced by the Giannini Plasmadyne Corp., the new process directly transfers the energy from an electric arc to an ionised gas medium. Temperatures created range up to 12,100 deg. C., six times the heat of a blast furnace. Despite the high velocities created (about 13,000 ft. per sec.) the jet is easily handled and is continuously monitored.

The combination of high temperature and velocity of the spray produces a very strong surface bond, high packing density, and a very smooth surface. In addition, the excellent thermal properties of the controlled spray coatings are expected to be quite useful in high temperature missile, aircraft and nuclear reactor application. Immediate applications are foreseen in providing low cost, lightweight protection for exposed structural parts such as high temperature pump and bearing surfaces, combustion chamber valves and liners, high speed grinding and cutting surfaces, and high temperature wiring insulation.

The new coating method has been used to spray vaporised tungsten on to cold steel. (The boiling point of tungsten is 4,100 deg. C. higher than any other element in the periodic table.) The tungsten coating has excellent adhesion and a tightly packed, smooth surface. Unlike chemical combustion processes, the inert jet does not contaminate or oxidise the coating or base material.

New Semi-conductors

Three intermetallic semi-conducting compounds—indium phosphide, gallium arsenide and aluminium antimonide—have been singled out as the most promising of the intermetallic compounds for use in high temperature transistors and rectifiers. A research programme recently initiated at Battelle Memorial Institute and sponsored by seven manufacturers and industrial users of electronic components is aimed at development and evaluation of these three compounds for transistors and rectifiers for operation in high temperatures and nuclear environments.

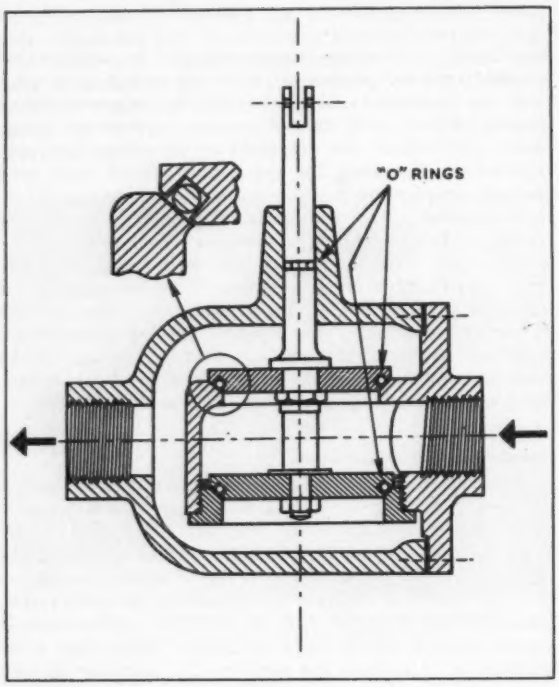
The large family of intermetallic compounds are relative newcomers to the semi-conductor field, complementing the established silicon and germanium metalloids. Such compounds show high promise of both broadening the operating limitations of semi-conductor devices, and permitting the development of entirely new devices. Their major areas of application appear to be in transistors and rectifiers, galvanomagnetic devices, heat sensitive resistors, optical devices, such as those making use of photovoltaic effects or of selective light transmission, and thermoelectric devices.

P.t.f.e-impregnated Bearing

A bearing announced by the Dixon Corp., consists of a steel-backed wire mesh impregnated with modified p.t.f.e. which is given a special surface treatment. While many variations are possible, the so-called Rulon S-Liner bearing consists of a 60 x 60 mesh woven phosphor-bronze screen bonded to a plated steel backing. The thickness of the plastic impregnant beyond the screen is about 0.006 in.

Because of the thinness of the plastic layer and the presence of the heat-dissipating wire mesh the bearings can be run at high loads and speeds. Cold flow is practically eliminated by this type of construction. Bearings have been run without lubrication for over 1000 hr. at PV values of 20,000 and under intermittent operation at PV values of 40,000. This compares with PV ratings of 500 to 2000 for nylon and 1000 for Teflon under similar conditions. (PV is the product of the bearing load in p.s.i. and the rubbing speed in ft. per min.)

Three Balanced-pressure Stop Valves

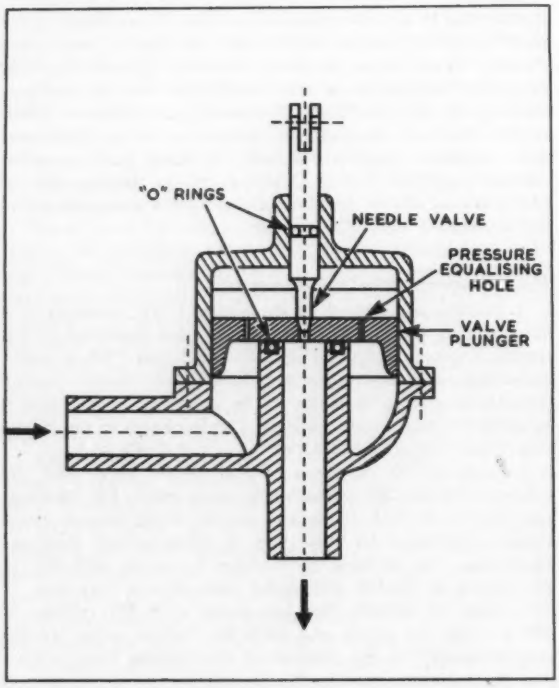


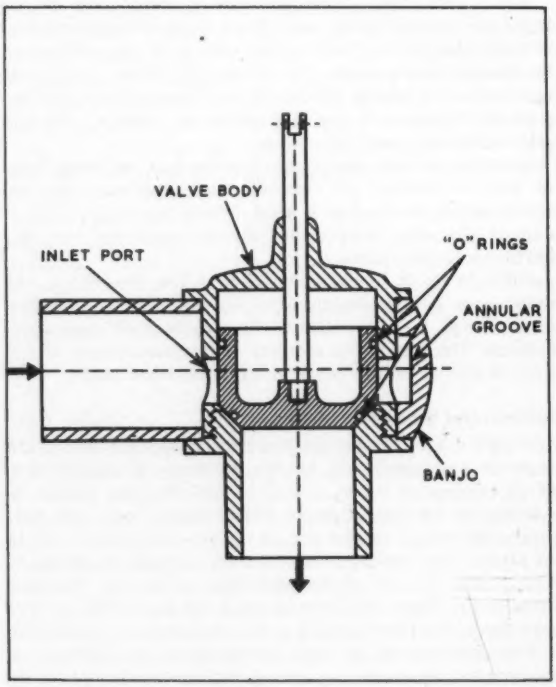
OCCASIONALLY, an on-off valve has to be provided which can be operated by small mechanical forces. When the valve is to pass a fluid under widely-varying pressures and the operating force required for the valve must remain nearly constant, the logical step is to provide some form of balanced valve. An example is provided by the type of valve required in a domestic washing-up machine, where wide variations in mains pressure are encountered. Illustrated in a semi-diagrammatic way on this page are the working pressures of three such valves.

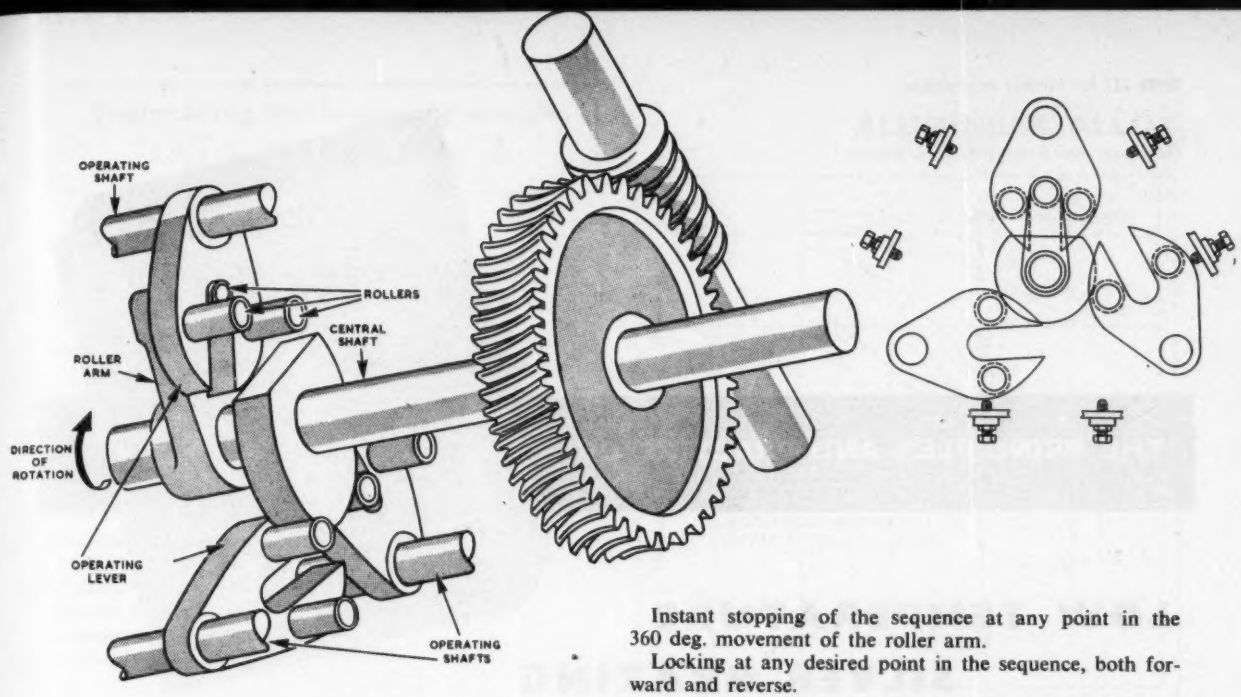
At *left* is shown a valve based on the double-beat stop valve used in steam work. Fluid pressure operates on two plungers of equal area. Opening and closing pressures being balanced, only a slight downward pressure on the plunger is required to ensure sealing. The valve is reversible.

The valve *below left* operates as follows: When closed, fluid pressure on both sides of the sliding plunger is equalised through small holes. The area of the upper surface of the plunger exposed to pressure being greater than that on the lower surface, the central portion of which is not exposed to pressure, there is a positive closing force on the plunger. Raising the needle valve opens a small port in the plunger and thereby drops the pressure in the upper part of the valve. The plunger rises and opens the outlet port. This type of valve is sometimes provided with a rubber diaphragm instead of the plunger shown.

In the valve illustrated *below*, fluid is supplied to a series of ports in the valve body by a banjo with an annular groove. The force required to operate the valve plunger is independent of fluid pressure.







Mechanism for Operating Three Shafts in Sequence

IN a Bristol aircraft air-conditioning installation it was necessary to provide a means whereby three shafts were each moved through 120 deg. in sequence.

Design requirements necessitated the following provisions:

Part or full arcuate movement of one shaft. Full arcuate movement of one shaft and partial movement of a second shaft. Full arcuate movement of two shafts and partial movement of a third. Full arcuate movement of all three shafts by full rotation of the central shaft.

Instant stopping of the sequence at any point in the 360 deg. movement of the roller arm.

Locking at any desired point in the sequence, both forward and reverse.

The drawing illustrates the mechanism that was devised. An arm fitted with a roller is carried on a central shaft which is rotated by a worm-gear. Equally disposed about this central shaft are three shafts, each of which is made to move through 120 deg. on its axis. To these are attached three fork-ended levers, each of which the roller on the arm of the central shaft engages in turn. When not being operated, each lever is restrained from arcuate movement by two projecting rollers, one of which, according to the direction of rotation of the central shaft, bears against a cylindrical enlarged portion of the central shaft.

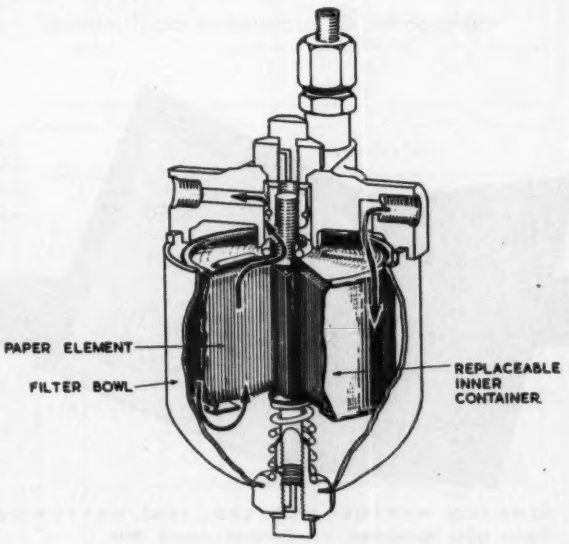
A flat on this enlarged portion allows movement of each fork-ended lever when the actuating roller engages the fork. Adjustable stop screws are provided to restrict excessive movement of the fork-ended levers.

Throwaway Unit in an Oil Filter

IT is sometimes possible to adapt metal packs such as tinplate cans, tins, boxes and spools or aluminium extrusions for use as components in engineering and domestic products. In some instances, the cost may be sufficiently low to treat the component as a disposable item. The large numbers in which such containers are made ensures very economic production and raw material accounts for the greater part of the cost.

An additional advantage is that the finished product in many cases can be supplied in finished form, being made from pre-printed sheet. Such products are usually built up with locked seamed joints which may be left dry, be composition lined or soldered. Shallow containers may have seamless drawn bodies. Many types of closure are possible: seamed-on ends, slip lids, screw caps, pouring necks, press caps, sprinklers and dispensers.

A good example of such a pack used as a disposable item is the container for the filter element in an oil filter manufactured by C.A.V. Ltd. The filter material employed is paper strip, wound round a cylindrical core in the form of a spiral. The strips are cemented together at top and bottom so as to form a series of V-shaped coils. A very large filter area is thus provided within a small compass. The actual number of turns of paper is much greater than depicted in the accompanying illustration. It will be seen that the dirty oil is confined to the undersides of the paper coils and filtered oil to the upper sides. Resin-treated paper is used which is claimed by the manufacturers to provide a marked superiority over the filtration materials usually employed.



THE PRINCIPLES AND PRACTICE OF

LOW TEMPERATURE SILVER BRAZING

FOR THE INTEREST AND INFORMATION OF ALL ENGAGED IN METAL JOINTING PRACTICE

The increasing adoption of the low temperature silver brazing technique for jointing ferrous and non-ferrous metals, the wide range of alloys and fluxes now available and the experience gained from their use in many industries have made it necessary to reorganise and amplify the existing technical data on this important subject.

This new series of data sheets covers many aspects of low temperature brazing—selection of alloys and fluxes, applications and operation. Together these sheets will constitute an important source of reference for all interested in metal jointing.

The first data sheets are now in print and further sheets will be issued at monthly intervals. A special binder will also be available shortly. May we add your name to our mailing list?

Johnson Matthey

JOHNSON, MATTHEY & CO. LTD., 73/83, HATTON GARDEN, LONDON, E.C.1 Telephone: HOLborn 6989
Vittoria Street, Birmingham, 1. Telephone: Central 8004. *75/79, Eyre Street, Sheffield, 1. Telephone: 29212.*

B82

Engineering Materials and Design

DATA SHEET No. 3

ALUMINIUM ALLOY

Forging Stock (Solution Treated and Aged)

Fulfilling B.S.S. L.65 (Aircraft)
and B.S.S. 1472; HF. 15 (General Engineering)
(4.4% Cu., 0.7% Mg., 0.7% Si., 0.6% Mn.)

Heat Treatment:	
Solution treatment	2-4 hr. at 500-510°C. and quench in water
Artificial ageing	5-20 hr. at 155-185°C.
Annealing Treatment:	2 hr. at 360°C. and cool slowly
Density (at 20°C.):	2·79 gm./cm.³ (0·101 lb./in.³)
Specific Heat (mean values over range 20-100°C.):	0·21 cal./gm.
Thermal Conductivity (at 20°C.):	0·27 cal./cm. sec.°C.
Melting Point:	530-610°C.
Specific Resistance:	4·1 microhms/cm.³
Coefficient Linear Expansion (20-200°C.):	0·000023

Minimum Specification Properties

	Extruded Forging Stock			Rolled Forging Stock
	¾ in. to 1 in.	1 in. to 4 in.	4 in. to 8 in.	
L.65				
U.T.S.	p.s.i.	p.s.i.	p.s.i.	p.s.i.
longitudinal	67,000	72,000	67,000	67,000
0·1% proof	58,000	63,000	58,000	58,000
HF.15				
U.T.S.				
longitudinal		67,000 p.s.i.		
0·1% proof		56,000		
Elongation (L65 and HF.15)		8%		

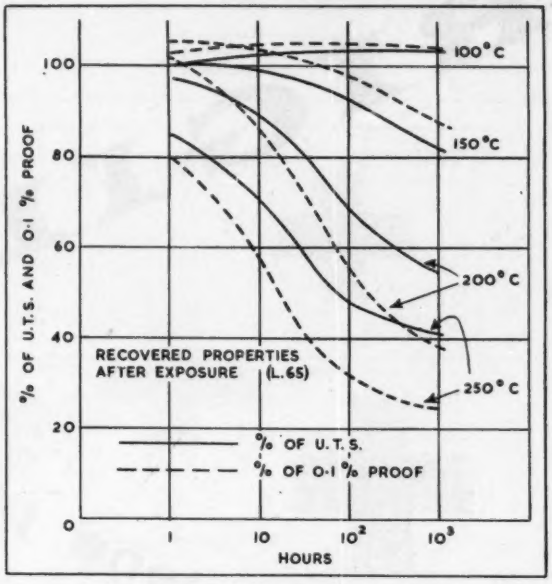
Modulus of Elasticity (E): 10—10.5 × 10⁶
Modulus of Rigidity (G): 3·9 × 10⁶
Yield in Bearing (approx.): 78,000 p.s.i.

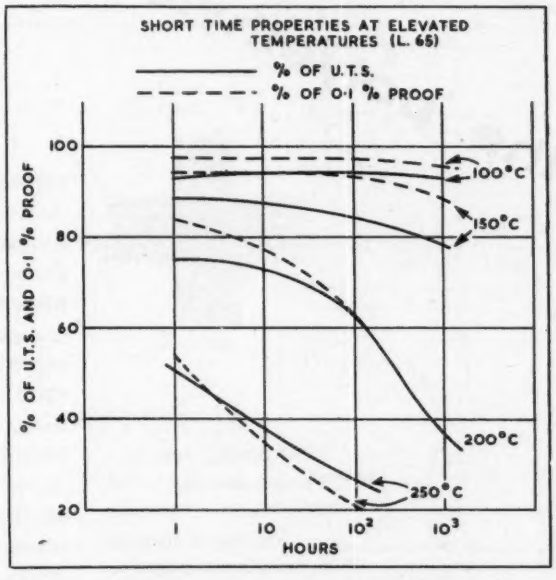
Proprietary names for materials to the above specifications:

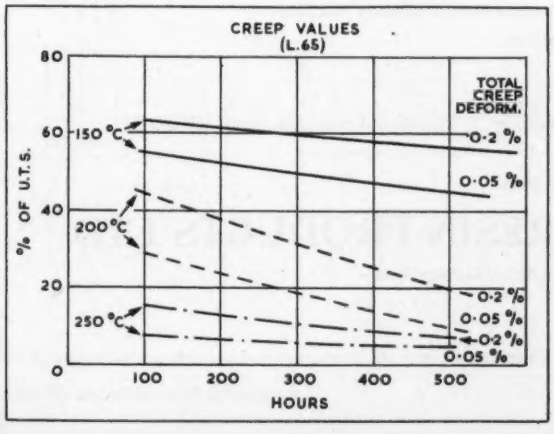
Alminal	W.15	Kynal	C.66
Birmetal	478	Noral	B.26S
Duralumin	S	T.I.	667
Hiduminium	66		

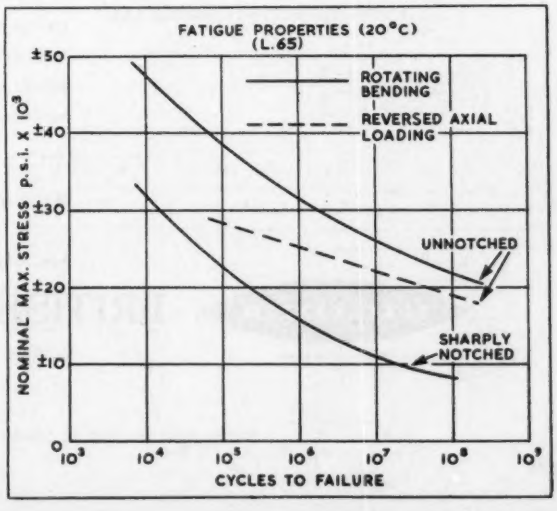
NOTE: Typical properties exceed the minimum quoted.

L. 65 data based on A.G.A.R.D. *Materials Properties Handbook* by courtesy of The Royal Aeronautical Society.





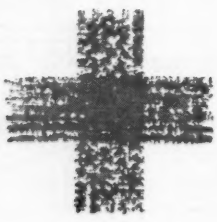




EMD 133 for further information

RIGIDEX

the polyethylene plus



RIGIDEX—the **new** polyethylene . . . the **rigid** polyethylene—extends the limits of all-plastics design. Now introduced by B.R.P., it surpasses materials previously available in many essential properties and range of engineering uses.

RIGIDEX is stronger, tougher, more rigid. Makes thinner sections possible. Brings lightness, durability and impact resistance to all fabrications.

RIGIDEX has higher softening temperature. Does not melt in boiling water. Can be autoclaved.

RIGIDEX resists acids, alkalis, oils. Gives maximum protection in laboratories and on the plant.

RIGIDEX looks cleaner, feels fresher. Mouldings possess exceptional surface finish . . . can be produced in wide range of colours . . . are pleasant to the touch. Film is impervious to vapour and moisture.

RIGIDEX is easier to fabricate. Perfectly reproduces design detail. Extruded material is easily machined—easily assembled.

RIGIDEX is made by a process developed by the Phillips Petroleum Company who have licensed the manufacturing rights to British Hydrocarbon Chemicals Ltd.

Write for Booklet 317 giving information about **RIGIDEX**

Sole Selling Agents

RIGIDEX

REGD. TRADE MARK

BRITISH RESIN PRODUCTS LTD

A Member of the Distillers Plastics Group

SALES AND TECHNICAL SERVICE DEVONSHIRE HOUSE PICCADILLY LONDON W1 HYDE PARK 0151

FORMULÆ FOR PRESSURES BETWEEN SOLID ELASTIC BODIES

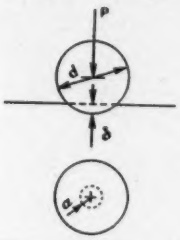
(Generalised Expressions)

Engineering Materials and Design
DATA SHEET No. 4

P = applied load (lb.)
p = load per linear in.
f_c = max. compressive stress between bodies (p.s.i.)
δ = max. total deformation (in.)

a = radius of contact area (in.)
b = width of contact area (in.)
d = dia. of sphere or cylinder (in.)

R = radius of seating (in.)
E = Modulus of elasticity (p.s.i.)
ν = Poisson's ratio



$$a = 0{\cdot}721 \sqrt[3]{Pd\left[\frac{1-\nu_1^2}{E_1}+\frac{1-\nu_2^2}{E_2}\right]} \qquad f_c = 0{\cdot}918 \sqrt[3]{\frac{P}{d^2\left[\frac{1-\nu_1^2}{E_1}+\frac{1-\nu_2^2}{E_2}\right]^2}}$$

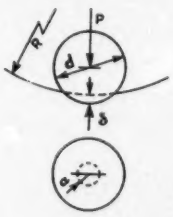
Where $E_1 = E_2 = E$ and $\nu_1 = \nu_2 = 0{\cdot}3$

$$a = 0{\cdot}881 \sqrt[3]{\frac{Pd}{E}} \qquad f_c = 0{\cdot}616 \sqrt[3]{\frac{PE^2}{d^2}} \qquad \delta = 1{\cdot}55 \sqrt[3]{\frac{P^2}{E^2 d}}$$

$$a = 0{\cdot}721 \sqrt[3]{P\left(\frac{2Rd}{2R+d}\right)\left(\frac{1-\nu_1^2}{E_1}+\frac{1-\nu_2^2}{E_2}\right)} \qquad f_c = 0{\cdot}918 \sqrt[3]{\frac{\left(\frac{2R+d}{2Rd}\right)^2}{P\left[\frac{1-\nu_1^2}{E_1}+\frac{1-\nu_2^2}{E_2}\right]^2}}$$

Where $E_1 = E_2 = E$ and $\nu_1 = \nu_2 = 0{\cdot}3$

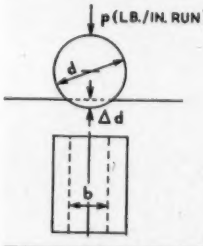
$$a = 0{\cdot}881 \sqrt[3]{\frac{P}{E}\cdot\frac{2Rd}{2R+d}} \qquad f_c = 0{\cdot}616 \sqrt[3]{PE^2\left(\frac{2R+d}{2Rd}\right)^2} \qquad \delta = 1{\cdot}55 \sqrt[3]{\frac{P^2}{E^2}\cdot\frac{2R+d}{2Rd}}$$



$$a = 0{\cdot}721 \sqrt[3]{P\frac{2Rd}{2R-d}\left[\frac{1-\nu_1^2}{E_1}+\frac{1-\nu_2^2}{E_2}\right]} \qquad f_c = 0{\cdot}918 \sqrt[3]{\frac{\left(\frac{2R-d}{2Rd}\right)^2}{P\left[\frac{1-\nu_1^2}{E_1}+\frac{1-\nu_2^2}{E_2}\right]^2}}$$

Where $E_1 = E_2 = E$ and $\nu_1 = \nu_2 = 0{\cdot}3$

$$a = 0{\cdot}881 \sqrt[3]{\frac{P}{E}\cdot\frac{2Rd}{2R-d}} \qquad f_c = 0{\cdot}616 \sqrt[3]{PE^2\left(\frac{2R-d}{2Rd}\right)^2} \qquad \delta = 1{\cdot}55 \sqrt[3]{\frac{P^2}{E^2}\cdot\frac{2R-d}{2Rd}}$$

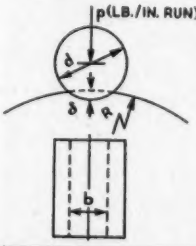


$$b = 1{\cdot}6 \sqrt{pd\left[\frac{1-\nu_1^2}{E_1}+\frac{1-\nu_2^2}{E_2}\right]} \qquad f_c = 0{\cdot}798 \sqrt{\frac{p}{d\left[\frac{1-\nu_1^2}{E_1}+\frac{1-\nu_2^2}{E_2}\right]}}$$

Where $E_1 = E_2 = E$ and $\nu_1 = \nu_2 = 0{\cdot}3$

$$\Delta d = 4p\left(\frac{1-\nu_1^2}{\pi E}\right)\left(\frac{1}{3}+\log_e\frac{2d}{b}\right) \qquad b = 2{\cdot}15 \sqrt{\frac{pd}{E}} \qquad f_c = 0{\cdot}591 \sqrt{\frac{pE}{d}}$$

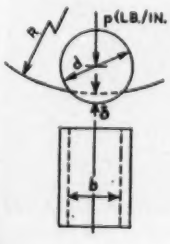
(Total compression between two plates)



$$b = 1{\cdot}6 \sqrt{p\frac{2Rd}{2R+d}\left[\frac{1-\nu_1^2}{E_1}+\frac{1-\nu_2^2}{E_2}\right]} \qquad f_c = 0{\cdot}798 \sqrt{\frac{p\left(\frac{2R+d}{2Rd}\right)}{\left[\frac{1-\nu_1^2}{E_1}+\frac{1-\nu_2^2}{E_2}\right]}}$$

Where $E_1 = E_2 = E$ and $\nu_1 = \nu_2 = 0{\cdot}3$

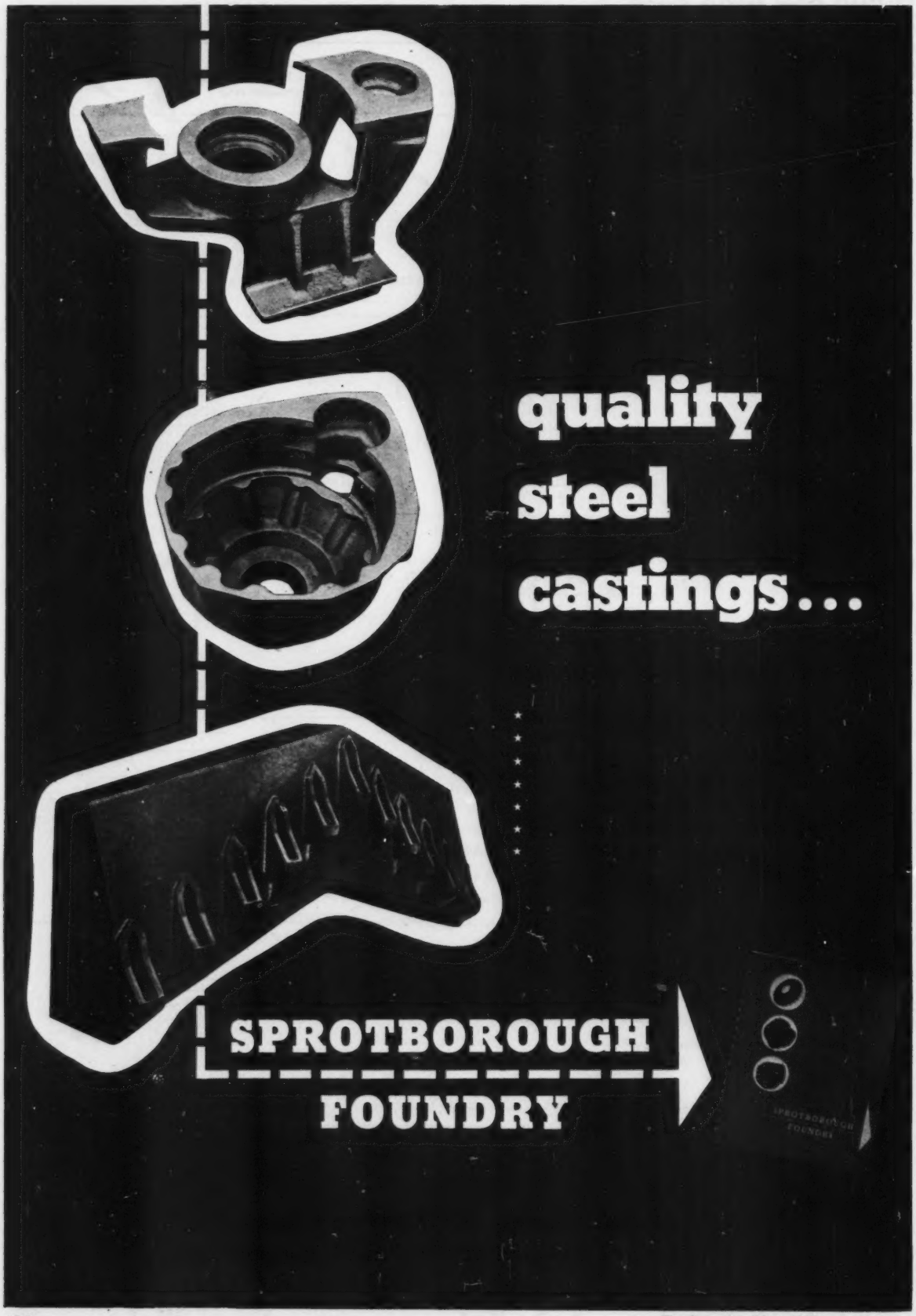
$$b = 2{\cdot}15 \sqrt{\frac{p}{E}\cdot\frac{2Rd}{2R+d}} \qquad f_c = 0{\cdot}591 \sqrt{pE\left(\frac{2R+d}{2Rd}\right)} \qquad \delta = \frac{2(1-\nu^2)}{E}\cdot\frac{p}{\pi}\left(\frac{2}{3}+\log_e\frac{4R}{b}+\log_e\frac{2d}{b}\right)$$



$$b = 1{\cdot}6 \sqrt{p\left[\frac{2Rd}{2R-d}\right]\left[\frac{1-\nu_1^2}{E_1}+\frac{1-\nu_2^2}{E_2}\right]} \qquad f_c = 0{\cdot}798 \sqrt{\frac{p\cdot\frac{2R-d}{2Rd}}{\left[\frac{1-\nu_1^2}{E_1}+\frac{1-\nu_2^2}{E_2}\right]}}$$

Where $E_1 = E_2 = E$ and $\nu_1 = \nu_2 = 0{\cdot}3$

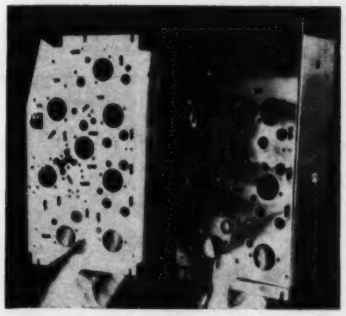
$$b = 2{\cdot}15 \sqrt{\frac{p}{E}\cdot\frac{2Rd}{2R-d}} \qquad f_c = 0{\cdot}591 \sqrt{pE\left(\frac{2R-d}{2Rd}\right)}$$


quality
steel
castings...
SPROTBOROUGH
FOUNDRY

WHAT'S NEW IN MATERIALS & COMPONENTS

Bright Tin-plating

A tin-plating solution, known as Brytin, which is claimed to produce a fully bright deposit without polishing or scratch-brushing, has recently been developed. The process of plating involves the use of a brightener made from wood tar by a special process, and a revivifying agent has also been developed for addition to old baths when a decline takes place in the brightness of the deposits produced. One of the main advantages of bright plating is for parts which are



subsequently soldered, as a bright finish is not perceptibly marked by handling, whereas the normal dull finish readily accepts fingerprints. Sonil Engineering & Equipment Ltd.

EMD 162 for further information

Creep-resisting Alloy

Nimonic 105, a further heat- and creep-resisting alloy in the Nimonic series, has recently been introduced. It is a development of the nickel-chromium-cobalt-molybdenum alloy Nimonic 100 and shows a useful advance in high-temperature properties. It has greater resistance to creep at very high operating temperatures than Nimonic 100, the minimum life to rupture at 7 tons per sq. in. and 940 deg. C. being 50 hours.

An important advantage of Nimonic 105 is its improved resistance to a specific type of high-temperature corrosion sometimes experienced in aero and other gas turbines running at elevated gas temperatures.

Nimonic 105 has already been tested by the British aero-engine industry and is now in production. Henry Wiggin & Co. Ltd.

EMD 163 for further information

P.t.f.e. Tape

P.t.f.e. film is now being made available in this country in an unsintered form permitting easy fabrication into a range of products which can be built up by lapping. It is supplied in a tape, under the name of Bonnytape, and is available in a range of colours, in widths from ¼ in. to 3 in. and in thickness from 3-10 thou. The tape is produced by a special calendering process, resulting (according to the makers) in a virtually fault-free film of considerable strength. In this form it is easily lapped on to the required former, after which it is sintered for a short period at 380-395 deg. C. During this sintering operation shrinkage occurs, thus ensuring complete fusing at the lap joints. Tensile strength of the tape is 1,250-2,000 p.s.i. unsintered and 6,000-6,500 p.s.i. sintered. Durham Raw Materials Ltd.

EMD 164 for further information

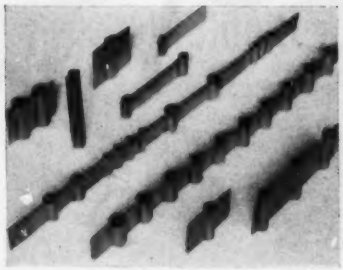
Heat Insulation

A new insulation panel, intended primarily for use in industrial and institutional buildings but with a range of other possibilities, has recently been introduced. This thermal-acoustic panel is claimed to have equally good qualities in both fields, as well as being highly decorative. Two feet square, with a jig-made timber frame, each panel has a filling of incombustible mineral wood sandwiched between a sheet of perforated hardboard and a backing of kraft. Filling is prevented from falling through the holes by a thin fibrous skin. The panels are joined by hardboard splines falling into slots, finished in a choice of washable colours, and are fixed either by secret nailing, concealed clips or a special metal fixing system. Bowater Organisation.

EMD 165 for further information

Tube-in-Strip

A non-ferrous material in a form which combines tube and strip in one product has recently been developed. This is called Tube-in-Strip, and is a combination of parallel tubes and strip material. The tubes, in fact, form an integral part of the sheet. This form of construction is to ensure reliability and



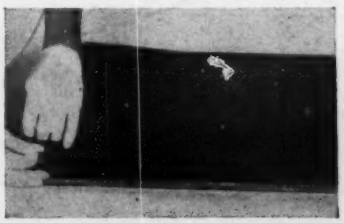
uniformity of heat-transfer conditions and allows the full mechanical properties of the material to be exploited.

The product is at present being made in commercially-pure aluminium and deoxidised copper, but the range will probably be extended later to aluminium and copper alloys. Present sizes available are up to 22 in. for aluminium. Tube diameters are from ¼ in. to 1 in. Among suggested applications are motor radiators and heaters, refrigerant panels and heat-transfer equipment for the chemical and oil industries. I.C.I. Ltd.

EMD 166 for further information

Honeycomb Brazing Sheet

A new Nicrobraz sheet is available for use with stainless steels, high alloys and titanium. The sheet is said to be particularly suitable for the brazing of



honeycomb structures for high-temperature service and, being flexible, it readily conforms to contoured surfaces. Sheet thicknesses from 0·005 in. and widths from 2 in. to 2 ft. are available. One pound of 0·005-in. sheet will cover approximately 18½ sq. ft. of area. Wall Colmonoy Ltd.

EMD 167 for further information

Zinc-rich Paint

A new paint claimed to protect iron and steel as effectively as hot-dip galvanising is Glopane. This paint consists of an atomised zinc dust carried at an exceptionally high concentration in a specially selected plastic medium. The dried film is said to contain 95 per cent by weight of zinc and, as with a galvanised surface, protects the underlying steel by electrolytic action so that a completely unbroken film is not essential. The paint is available in a number of forms for application to dry surfaces, for site application where absolute dryness cannot be obtained or for conditions where resistance to oils and greases is necessary; a special two-part material is supplied where a high degree of solvent resistance is required. J. H. Sankey & Son Ltd.

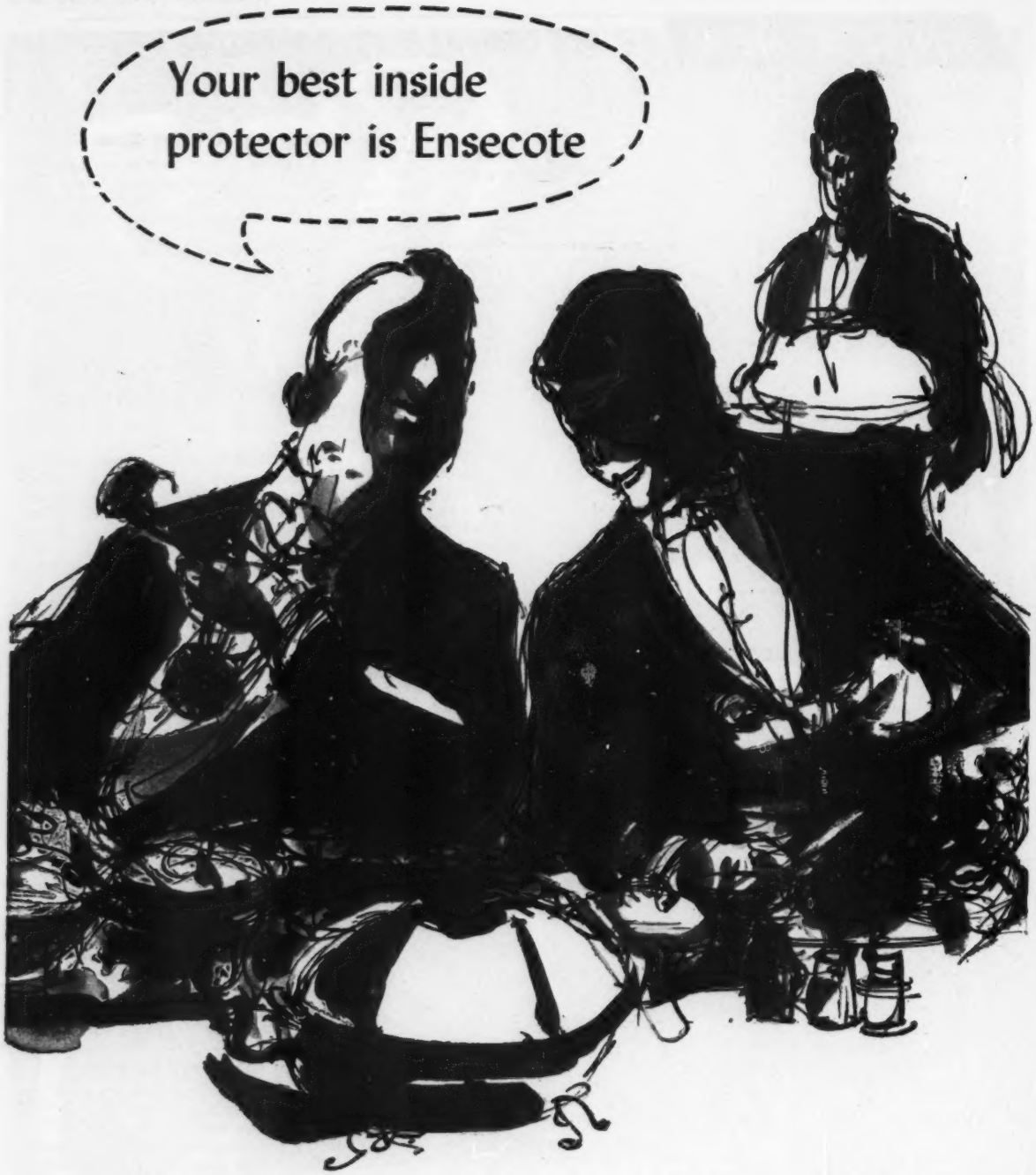
EMD 168 for further information

Linings for Heavy Industry

Hexmetal cellular reinforcement is now being used by heavy industry for protective linings and refractories of blast furnaces, dust collectors and coke bunkers. This material is a fabrication of steel-walled honeycomb cells which,

FOR MORE INFORMATION
about any of the products mentioned on these pages, please use the special reply card bound in this issue.

READERS' ADVISORY SERVICE
We shall be pleased to help readers who have difficulty in tracing sources of supply of materials or components.



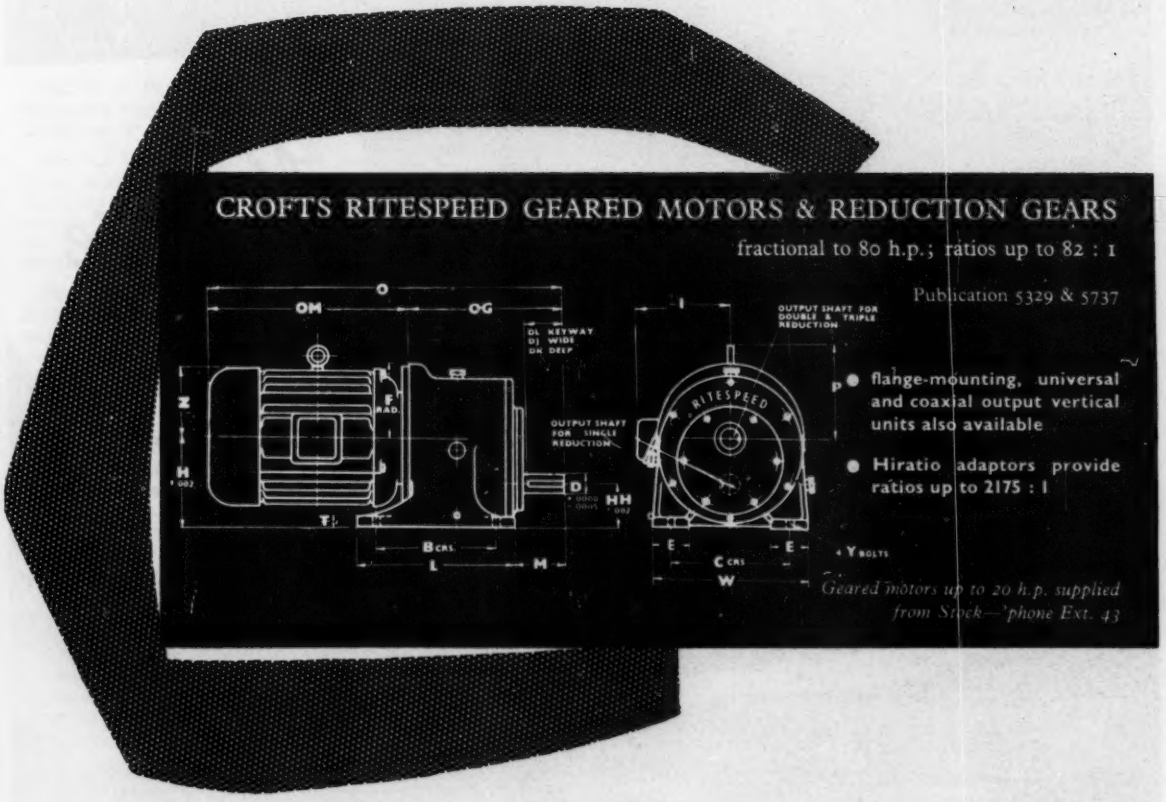
People who pride themselves on their good equipment speak of ENSECOTE in a personal way. ENSECOTE protective plastic linings can be applied almost anywhere to almost anything. They are easily cleaned and sterilised, completely odourless, tasteless—and economical to install because larger vessels can be lined on the spot. ENSECOTE is particularly useful, too, for renovating glass lined tanks. The Dairy, Brewing, Paper and Chemical Industries—and all who own rail and road storage tanks —will find ENSECOTE invaluable as a protection against wastage due to deterioration.

ENSECOTE

Lithcote PLASTIC LININGS

For literature and technical advice write to:
NEWTON CHAMBERS AND CO., LTD.
THORNCLIFFE, NR. SHEFFIELD, ENGLAND
Agents in Belgium, France and Holland:
FOURS LECOCQ ET ATELIERS DE TRAZEGNIES REUNIS, SA., TRAZEGNIES, BELGIUM

design for productivity



with power transmission equipment by Crofts of Bradford

makers of: *Clutches, Conveyor Drives, Couplings of all types, Double helical gear units, Fabricated steelwork, Geared motors, Hydraulic couplings, Iron, steel and non-ferrous castings, Machine-cut gears of all types, Motorised rollers, Patent Taper-flush-bushes, Plummer blocks, Shaft-mounted gear units, Special machinery drives, Spiral bevel gear units, Turbine gears, V-Rope Drives, Variable speed drives, Worm reduction gears.*

no modern design department should be without a comprehensive set of Crofts Technical Publications Bona fide requests will be dealt with promptly by our Publicity Department at Bradford, or by any of the Branch Offices at: Belfast, Birmingham, Bristol, Cardiff, Dublin, Glasgow, Ipswich, Leeds, Liverpool, London, Manchester, Newcastle, Northampton, Nottingham, Sheffield, Stoke-on-Trent

CROFTS (ENGINEERS) LIMITED

POWER TRANSMISSION ENGINEERS

Head Office: Thornbury Bradford 3 Yorkshire

Telephone: 65251 (20 lines) Telegrams: "Crofters Bradford Telex" Telex 51186

Resin suppliers: British Industrial Plastics

When Jenny the Bertram Mills elephant stood on a Fibreglass Reinforced Plastic tub, she made no impression, but she made history—in a way. However, elephant-resistance is one thing: corrosion-resistance is another. It is when the two are combined—moulded into a one-piece bucket for a detergent conveyor—that you have a message for the chemical industry. Lightweight F.R.P. doesn't buckle, warp, drum or dent either. What it can do, and not do, for your business is a matter Fibreglass technicians would like to discuss.

FIBREGLASS
TRADE MARK

the backbone of corrosion-resistant plastics

FIBREGLASS LIMITED, ST. HELENS, LANCASHIRE. TELEPHONE: ST. HELENS 4224

News of Industry

Mr. A. Kimpton has joined Elliott-Automation Ltd. as chief draughtsman in that firm's nuclear division.

Mr. E. W. Estill, until recently chief draughtsman of the guided weapons division of E.M.I. Electronics Ltd., is now works manager at Aldershot for Lawes Bros. Ltd., drawing material manufacturers.

Mr. B. A. Poppe has been appointed design engineer with Aluminium Laboratories Ltd. at Banbury.

Mr. A. Wallis, who has been with Edgar Allen & Co. since 1936, has been appointed chief draughtsman (production) for the company. **Mr. J. D. Lee** has been appointed chief draughtsman (development).

Dr. Richard Weck, director of the British Welding Research Assoc., is to lecture at a seminar on residual stresses being held by the American Society for Metals at the end of October at Cleveland, Ohio.

Mr. J. A. Grainger, a partner in European Industrial Consultants Ltd., and **Mr. A. G. Thompson,** an industrial engineering consultant, have been awarded medals by the Institution of Production Engineers for the best papers presented in 1956-7 by a member and non-member respectively.

Mr. Morton Gordon has been appointed acting chief welding engineer, Metal and Pipeline Endurance Ltd.

Mr. W. H. Glass, a director of Thermotank Ltd. for 25 years and designer of many of the company's installations and equipment, has retired.

Mr. J. M. Smith has been appointed by Armstrong Siddeley Motors Ltd. as chief designer responsible for design and installation work relative to the Maybach engines.

Mr. A. Kennaway has resigned as head of the experimental engineering section of the I.C.I. plastics division, to become assistant on plastics to the chief technical engineer of the Metal Box Co. Ltd.

The materials sections of the engineer-in-chief's department of the **Admiralty** have been amalgamated with other material groups to form a ship department. The deputy engineer-in-chief (material) responsible at present for the immediate direction of these sections will be the director of the marine engineering division of that department.

A one-day conference on "Industrial Design and the Engineering Industries" is being sponsored on November 12 at the Birmingham Engineering Centre by the **Council of Industrial Design.** It will be the first of its kind in the U.K. and will be attended by an invited audience of engineering executives mostly from the Midlands. It will deal with ways of encouraging an appreciation of appearance design in the engineering trades, and will examine the introduction of some training in industrial design into engineering courses.

Price reductions for Araldite epoxy resins have been announced by **CIBA (A.R.L.)** Ltd., following an increase in production capacity at their new factory.

A 15-minute colour film, entitled "More for Your Money", has been released by **Brook Motors Ltd.,** introducing a new design of electric motor, the C type, to B.S. 2960: 1958.

Executives and sales divisions of **Whiffen & Sons Ltd.** are now located at the company's Loughborough factory, with immediate effect.

At the Hereford works of **Henry Wiggin & Co. Ltd.,** built originally by the Ministry of Supply for the production of Nimonic alloys, the first stage in the modernisation and concentration plan has been completed. Erection of the plant commenced in 1951, the first ingot being extruded in 1954. In 1956 the company purchased the works from the Ministry with the aim of concentrating all production there. The present building coverage is about seven acres; by 1965, however, it is planned to complete the programme and have approximately 25 acres of the 52-acre site covered with works, laboratory and office buildings.

Sole selling rights for the pneumatic tools manufactured by Gebr.Bohler & Co., Vienna, have been acquired by **Tilghmans Ltd.,** of Altrincham.

A new welding laboratory is to be opened at the **Matthew Boulton Technical College** in Birmingham. The lecturer in charge of welding courses, Mr. R. G. Blackburn, says that the ever-increasing use of welding processes in atomic energy, shipbuilding, aircraft design and other fields will increase the demand for trained welders and engineers.

A new formaldehyde plant has just been put into operation in Hamburg by **Reichold Chemie A.G.** Annual production is expected to be about 5,000 tons. The company is also expanding its phthalic anhydride unit.

A new electric resistance weld mill, which can produce E.R.W. steel tubes up to 5½ in. diameter, with a wall thickness of ¼ in. and in lengths up to 60 ft., has been designed by **Tube Products Ltd.** at Wednesfield.

Twenty glass-fibre lifeboats have been ordered by the **Orient Line** for its new ship, *Oriana,* the first to be equipped with such boats. Each boat is 36 ft. long and is moulded in one piece.

The Natural Rubber Development Board, at the forthcoming Public Works Exhibition at Olympia, is to show how the scope for rubber in engineering has been enlarged in recent years. Prominence will be given to rubber bridge mountings, new uses of rubber in concrete construction, crash doors, dockside fenders, pipe couplings and anti-vibration mountings.

Designer's Diary

METALS

Oct. 22. Gauge and Tool Makers Assoc. Luncheon. Savoy Hotel, London. 12.15 p.m.

Oct. 23. Inst. Prod. Eng. "Alloy Steels". Royal Empire Society, London, W.C.2. 7 p.m.

Oct. 28. Nickel and Nickel Alloys Exhib. (Henry Wiggin & Co.) Grand Central Hotel, Belfast.

Oct. 28. Symposium on Aluminium Pressure Vessels. London. (Inst. of Mechanical Engineers.)

Nov. 7. I. Mech. E. talk: "Economic Design of Light Alloy Castings". 6 p.m. 1 Birdcage Walk.

PLASTICS

Oct. 6-Nov. 24. Series of lectures and films on plastics for non-technical members of industry. City of London College. Mondays at 6.15 p.m.

Oct. 21-24. Reinforced Plastics Technical Conference. Brighton. (British Plastics Federation.)

Oct. 23. Inst. of Prod. Engineers. "Plastics Material in Engineering". Ruston Club, Lincoln. 7.30 p.m.

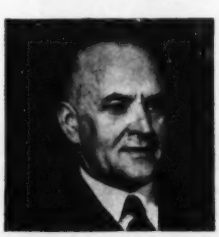
Nov. 18. P.I. talk on "Commercial and Cost Considerations in Injection Moulding". 183 Euston Road, London, N.W.1. 6.30 p.m.

GENERAL

Oct. 21-23. Symposium on Batteries. Ministry of Supply, Christchurch, Hants.

Oct. 21-23. Engineering Industries Assoc. Display. New Horticultural Hall, London.

Oct. 30. Start of refresher course for senior works and plant engineers. Liverpool University. (Inc. Plant Engineers.)



W. H. Glass

J. D. Lee

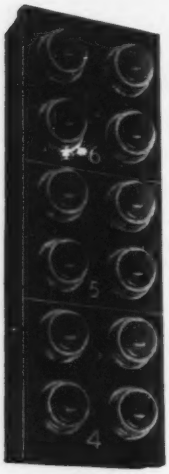
A. Wallis

EMD 139 for further information

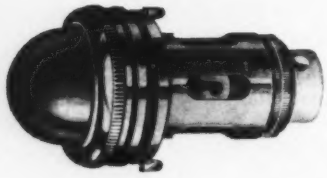
McGEOCH
INDICATOR LIGHTS

and

MULTI-LIGHT UNITS
to Customers' Requirements



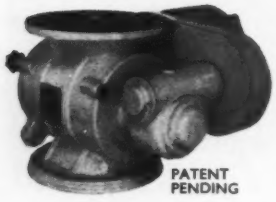
Registered
Estd. 1832
Trade Mark



also makers of
SWITCH and FUSE GEAR, CONTROL PANELS and CUBICLES, W/T SOCKETS and PLUGS, LIGHTING FITTINGS, LAMPHOLDERS, etc.

WILLIAM McGEOCH & CO. LTD. (Dept. D.M.E.), BORDESLEY, BIRMINGHAM 10, also at GLASGOW and LONDON

THE "DERION" *ROTARY AIRLOCK*
for discharging and feeding solids in pneumatic systems



PATENT PENDING

A precision built mechanical valve, providing maximum sealing efficiency with minimum maintenance and replacement parts.

★ Adjustable blades. The patented feature provides for wear adjustment without loss of initial sealing efficiency.

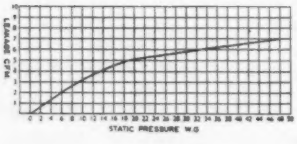
★ The rotor can be removed in 30 seconds without the use of tools.

★ All moving parts mounted on grease-packed sealed for "life" bearings which are external to the dust housing.

★ Robust construction.

★ Stove enamel finish for ease of cleaning.

★ Made in sizes from 0-3,000 cu/ft/hr.



Standard models supplied with integral gearbox and self-contained T.E.F.C. Motor Drive

Special drives on request:—Variable speed—direct-coupled geared motor—chain and sprocket etc.

Special Duties:—Units supplied in St. Steel, Nickel, Aluminium etc., Adjustable blades in Vitrathene, Mild Steel, Nylon, Fluon, Brass, Stainless Steel etc., etc.

SOLE MANUFACTURERS:— PHONE: BITTON 2131

BUSH AND WILTON LIMITED

THE OLD FOUNDRY, BITTON, NR. BRISTOL

EMD 141 for further information

EMD 140 for further information

"What's your name?"

More important still, do your customers see it on your products? Even assuming a "yes" to that question, does the way in which it is shown reflect credit on your firm?

There's only one way to be sure of a "yes" to that question; call in H. E. Peace and talk about transfers. There's no more complete transfer service available—quality, speed, efficiency and a first-rate design department, have all combined to make H. E. Peace the answer to transfer problems, for many, many firms.

Drop whatever you're doing and ask us to come and see you. You'll be glad you did!

PEACE *TRANSFERS*

HAROLD E. PEACE & CO. LIMITED · LUDGATE HILL · BIRMINGHAM 3

Make Light of Weight
AUTOSET CASTORS

Over 7,000 Types and Sizes.

Wheels 2" to 46" diameter.

Loads up to 30 TONS EACH.

Castor

Wheel Bracket

ASK FOR LIST No. 581/3/9

We also manufacture Extension Drawer Slides, Door Runners, Trucks and Trollies

ENGINEERS, PATENTEES & SOLE MANUFACTURERS

AUTOSET (PRODUCTION) LTD

ESTABLISHED 1919

69-73 STOUR STREET, BIRMINGHAM 18. *Phone: EDG 1143 (3 lines)*

EMD 142 for further information

Welded Fabrications

For the ultimate in Welded Fabrications consult Empyrium, pioneers in this field.

Transformer and Switchgear Tanks; Storage Tanks for Petrol, Oil and Water; Autoclaves; Chemical Plant of all descriptions; Bedplates; Machine Tool Press Frames; Gas Works Plant; Hoppers, Condensers, Gear Guards, Blast Mains, Air Receivers and Pressure Vessels of all types.

Empyrium fabricate for all industries to ASMI and Lloyds specification. Also to the exacting requirements of the Petroleum and Oil Companies. Single units up to twelve tons in weight. Full testing facilities.

EMPYRIUM

WELDING & MANUFACTURING COMPANY LIMITED

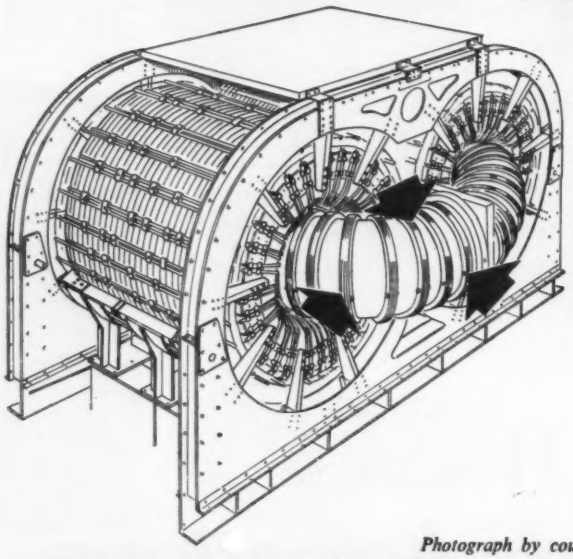
Head Office and Works: Pritchett Street, Birmingham 6.
Branch Works: Bagot Street, Birmingham 4.
Telephone: ASTon Cross 3203/4/5
Telegrams: Empyrweld Birmingham

PIONEERS IN WELDING PRACTICE SINCE 1917

JW Ad 4397

EMD 144 for further information

TURNERS DURAGLAS for Zeta



DURAGLAS glass fibre reinforcement was found to be the answer to the problems presented in the manufacture of the coil formers which support and position the auxiliary field winding on the torus in Zeta. These formers were produced by Permali Ltd., of Gloucester and supplied by them to Metropolitan-Vickers Electrical Co. Ltd., the main contractors for the construction of Zeta.

Let DURAGLAS answer your reinforcement problems — please send for further details.

Photograph by courtesy of Barratts Photo Press Ltd., London E.C.4.

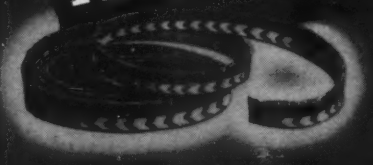
TURNER BROTHERS ASBESTOS CO. LTD. ROCHDALE ENGLAND

A MEMBER OF THE TURNER AND NEWALL ORGANISATION

dm TA 107

Stop draughts WITH

FLEXIBLE BRUSH WELT



As used by British Railways.

Hair or other specified materials and webbing provide a flexible draught excluder.

RIGID Kez-STRIP

Particularly useful for sliding-doors.

A variety of fillings firmly held in a continuous metal strip backing.

Full details from :

THE Kleen-e-ze BRUSH CO. LTD.

HANHAM · BRISTOL

EMD 145 for further information

'THE BEAUTY OF COLOUR — THE STRENGTH OF STEEL'

BURCOL

Plastic covered STEEL tubing ...

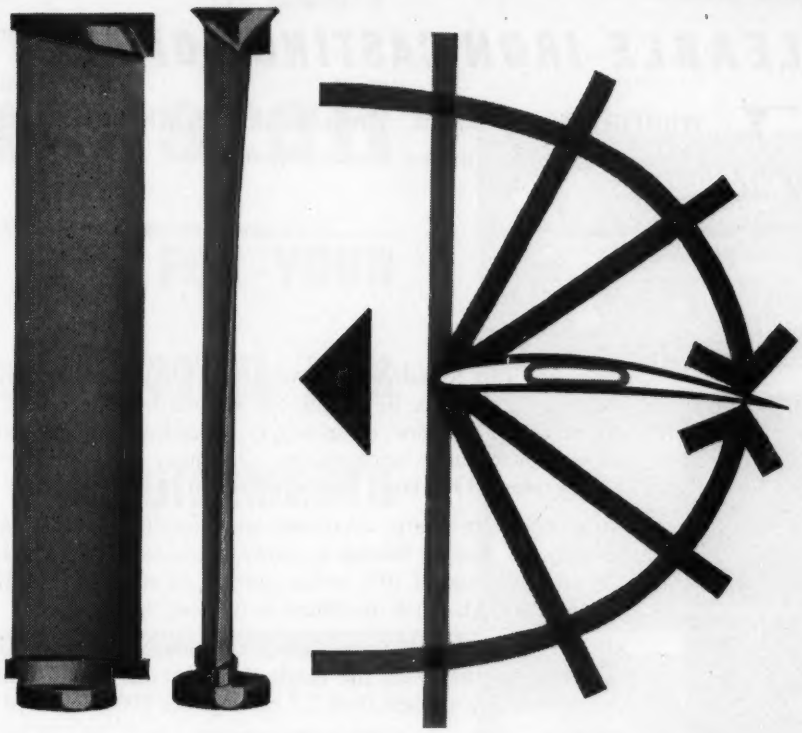
To meet YOUR needs

- NON-CORROSIVE
- INSULATING
- HYGIENIC
- PROTECTIVE
- ECONOMICAL
- DISTINCTIVE

LABURN LTD

BURCOL WORKS · RADWAY ROAD · SHIRLEY WARWICKSHIRE · TEL: SOLihull 2227-8

EMD 146 for further information



The illustration is shown by courtesy of Armstrong Siddeley Motors Ltd.

A new way with Hollow Blades

Wilmot Breeden, interested in the manipulation of metal in the cold state, have developed in co-operation with famous jet engine firms a new process for the manufacture of inlet guide vanes and stator blades. These envelopes are now formed in nickel-chrome alloys in a succession of press operations from a flat blank, the trailing edge being brazed—in a controlled protective atmosphere—to extremely close tolerances, leaving a minimum of material to be removed and eliminating any risk of weakening the joint.

The inlet guide vanes and stator blades determine the direction of flow of the air entering and passing through the compressor to the combustion chambers. Accuracy of the envelope is vital, particularly so at the trailing edge. The vane is anti-iced by passing hot air through it. This air is distributed by means of one or more perforated ducts, which may form strengthening members, positioned within the envelope. The benefits of this process are: minimum weight for given envelope size, full response to aerofoil requirements, maximum heat transfer because of uniform wall thickness, ease of accommodating end fixings of widely differing design.

The illustration shows an inlet guide vane for a Sapphire engine; the envelope and the single air duct of this blade are of stainless steel as are the spherical end bearing and the dovetail at the root end. Both end fixings are machined and ground to close tolerances after being brazed into position by induction heating.

If you have an application for this new method we should be pleased to investigate and advise.

Wilmot Breeden are skilled in metal manipulation

Wilmot Breeden Ltd, Birmingham 1

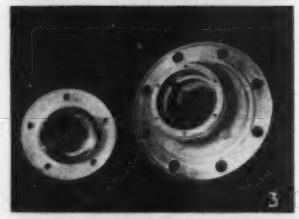
MALLEABLE IRON CASTINGS OF ALL TYPES

WHITEHEART · PEARLITIC · WELDABLE · BLACKHEART

(Produced to British Standard Specifications)

1

2


3

From our two foundries are available jobbing and repetition Malleable Castings up to 70lb. in weight, for agricultural machinery, automobiles and tractors, builders' ironmongery, electrical and general engineering. railway and similar applications. Our new, fully mechanised, foundry incorporates all the latest developments of foundry practice.

We specialise in sharp, accurately-sized castings combining strength and ductility. A unique feature is ready machineability, which we claim to give an advantage of 10% in fast cutting, so cutting costs. If required, we can supply work finish machined in our own shops.

All castings are subject to Quality Control using chemical-physical and sand laboratories, with the result that over the last 5 years our rejects from customers are less than 2.7 castings per 1000 delivered!

Special: Blackheart Castings which are still tough and ductile at sub-zero temperatures.

● We direct attention to our very high grade Pearlitic Malleable Castings, of exceptional strength and toughness.

●● Weldable Malleable Castings are of considerable interest to designers in solving production difficulties, as they can be combined with other materials into composite fabrications. Full particulars on request.

4

5

6

7

CASTINGS LIMITED

Castings for the following ndustries

(1) Agricultural
(2) & (3) Commercial vehicles
(4) & (5) General engineering
(6) Motor cycle
(7) Automobile

SELBORNE STREET, WALSALL, STAFFS. Tel: Walsall 3118-9 and Arboretum 55357 & 55378

Founded 1835

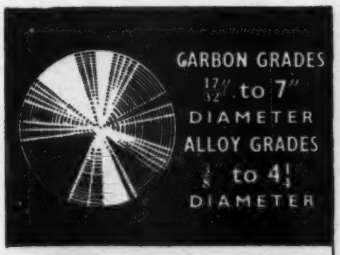
and at LICHFIELD ROAD, BROWNHILLS, STAFFS. Telephone: Brownhills 2318

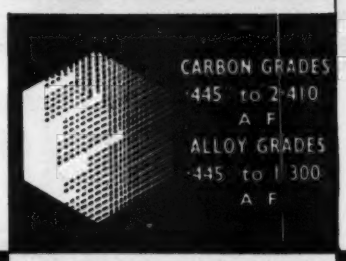
C3

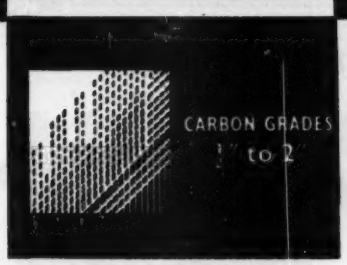
SPECIFY

Kirkstall

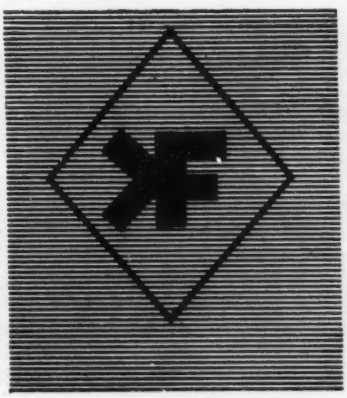
FOR YOUR BRIGHT STEEL BAR REQUIREMENTS







KIRKSTALL BARS can be supplied fully hardened and tempered, normalised or annealed according to specification requirements. We have facilities within our own organisation for cold drawing, centreless turning or grinding to precision or open limits. In addition to their productional functions, our laboratories, with their technical staff, are available to help you with any problem you may have.



KIRKSTALL FORGE
ENGINEERING LTD.
LEEDS, YORKSHIRE
Telephone: Horsforth 2821

If you would like a copy of our reference book "Tables and Data for Steel Users" which is a veritable mine of information, we would be pleased to let you have a copy.

EMD 150 for further information

Special Cocks & Fittings

We have been famous for the fine finish and accuracy of our products since 1872. You are invited to send for our catalogue which illustrates the complete range of Union Joints and Cocks. Our Lathe and Capstan Brasswork has a fine reputation in every trade. We look forward to your enquiries for special fittings.

Wm. WHITEHOUSE & Co. Ltd. Est. 1872

Empire Works, Brueton St., Birmingham, 4

SAFETY IN THE LONG RUN WITH THE . . . **C.J.R**

MAGNETIC SAFETY TRIP WIRE SWITCH

Designed specially for use with conveyors and similar equipment, where long runs of machinery are in use, this C.J.R. safety device stops the driving motor (or applies a brake), at a touch of the trip wire. You owe it to yourself and your employees to fit this infallible safety device.

MANUFACTURERS OF PORTABLE TOOL SAFETY SYSTEMS
INDUSTRIAL ELECTRONIC CONTROLS

ELECTRICAL AND ELECTRONIC DEVELOPMENT LIMITED
BICKFORD ROAD · WITTON · BIRMINGHAM 6

EMD 152 for further information

EMD 151 for further information

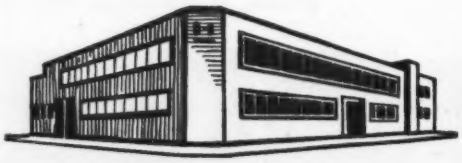
***S**pecialists in presswork*
***H**eavy and light*
***E**xperts in arc welding*
***L**arge quantities handled*
***L**esser ones welcomed*
***E**xceptionally good delivery*
***Y**our production problems solved*

in other words: "Shelley" spells the answer to presswork up to 120 tons capacity in all metals, coupled with excellent welding facilities and an up-to-date toolroom, we feel confident in our ability to quote you competitive prices.

L. SHELLEY LTD. *Manor Lane, Halesowen, Worcs.*
Telephone: HALesowen 2006/7

THE MIDLANDS LEADING STOCKISTS OF

ALUMINIUM
and its alloys



large comprehensive range always in stock in our warehouse

in the form of :—

tube, sheet, section, rod, wire and plate

mill quality at mill prices.

ACCREDITED STOCKISTS A.I.D. APPROVED

DEUTSCH & BRENNER
LIMITED

HARFORD STREET, BIRMINGHAM 19

Telephone Northern 3838 (11 lines)
Branches at Cardiff (31833) and Manchester (Gatley 6418)

EMD 153 for further information

GREENGATE & IRWELL RUBBER CO. LTD.

SPECIALISTS IN

TANK & PIPE LININGS

ALL TYPES

GREENGATE & IRWELL RUBBER CO. LTD.
IRWELL WORKS, ORDSALL LANE,
SALFORD 5, ENGLAND

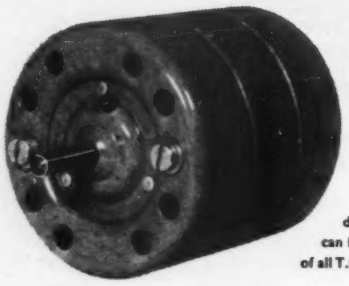
TELEPHONE: BLACKFRIARS 6622 (12 lines)

TELEGRAMS: 'PARA' PHONE MANCHESTER

There's power in plenty when you use

SHADED POLE MOTORS

by **T·I·M**



★ Silent
★ Versatile
★ Dependable
★ Vibration-free

Shaded Pole Fractional H.P. Type MC—Standard form with flange or foot mounting. Single or double shaft extensions can be supplied. Full details of all T.I.M. motors on request.

MYCALEX & T.I.M. LTD

CIRENCESTER, GLOS. Tel 400

To help you use electronics in design

COMMUNICATIONS & ELECTRONICS BUYERS' GUIDE

WHO'S WHO AND REFERENCE BOOK 1958/59

For the first time all available information on the products, firms and leading personalities associated with the British electronics industry has been brought together in a single volume. It includes a total of over 32,400 references.

This volume can help you to take advantage of progress in electronics

500 pp.: Size 11½ in. x 8¾ in. : 5 gns. post free.

Full descriptive leaflet available from the publishers

Order *your* copy of this time-saving volume TODAY from:

The Circulation Manager,
Heywood & Company Ltd.,
Drury House, Russell Street, London, W.C.2

SHELL MOULDED CASTINGS

in Steel

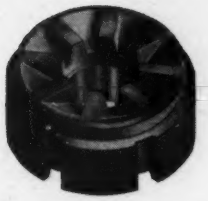
Alloy, Stainless and Carbon qualities

Accuracy of Dimensions and Coring
Excellent Definition
From ounces up to 50 lb. finished weight

THE Clyde Alloy STEEL CO LTD · MOTHERWELL

GEARS

and even more complex shapes produced without machining with DURASINT



Think of the savings you would make if you could eliminate machining! Impossible, you might think? No, not a bit of it. For so great are the advances made in recent years in powder metallurgy that it is now possible to produce a vast range of pieces **in their finished state!**

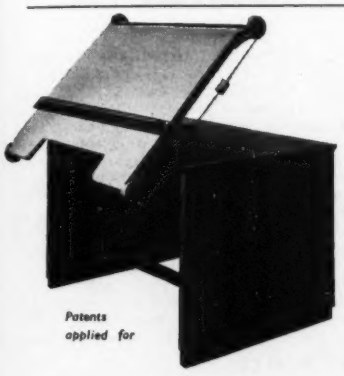
Already many manufacturers dealing in quantity production are taking advantage of these new techniques. And at Sintered Products Limited, still further applications are being found daily to help industry achieve a faster, more economic production of parts. Perhaps they could help you?

Our Representative will gladly call to discuss your particular problems. Or write for the DURASINT booklet giving you full details to:

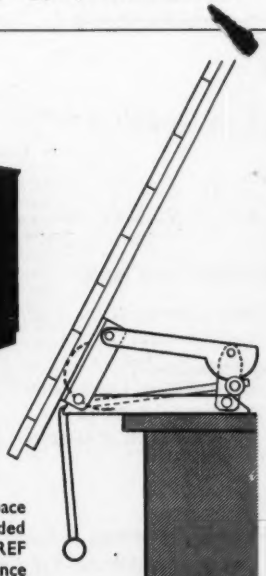
Sintered Simon says
Save on SINTERED

Sintered Products Ltd.
(One of the Sheepbridge Engineering Group)
Hamilton Road, Sutton-in-Ashfield, Notts.
Telephone: Sutton-in-Ashfield 590 Telegrams: Sintered, Sutton-in-Ashfield

---



Patents applied for



'UNI-REF'

A saving of 12%—15% on floor space is the immediate advantage afforded by the installation of the UNI-REF Combined Drafting and Reference Table. The unique pivoting device which makes possible this economy provides also a reasonably low horizontal working height, yet allows easy reach of all the drawing area when the board is in the vertical position, and obviates the necessity for height adjustment of boards below Hamburg size. For fuller details of these and other advantages of the UNI-REF equipment send for leaflet No. XF. 428/R/CE.

Haldens

J. HALDEN & Co. Ltd. (Dept E.M.D.) ROWSLEY WKS., REDDISH, STOCKPORT

---

send your difficult problems to

Blackburn

DUMBARTON

DESIGN & PRODUCTION

Our design experience and production facilities can save you time and money

- ★ Welding
- ★ Precision Machining
- ★ Sheet Metal Work
- ★ Structural Fabrication and Erection
- ★ All treatments

BLACKBURN (DUMBARTON) LTD.
Castle Road Dumbarton Scotland
Telephone: Dumbarton 441 (7 lines)

INDEX TO ADVERTISERS

A

Allen, Edgar, & Co., Ltd. 2A
Autoset (Productions) Ltd. 116

B

Blackburn (Dumbarton) Ltd. 27A
Bray, George, & Co. Ltd. 15A
British Nylon Spinners Ltd. 11A
British Resin Products Ltd. 104
Bush & Wilton Ltd. 116
B.X. Plastics Ltd. 18A

C

Castings Ltd. 22A
Clyde Alloy Steel Co. Ltd., The 26A
C.J.R. Electrical & Electronic Development Ltd. 24A
Crofts (Engineers) Ltd. 113
Cruickshank, R., Ltd. 9A

D

Deutsch & Brenner Ltd. 24A

E

Empyrium Welding & Manufacturing Co. Ltd. 19A

F

Fibreglass Ltd. 114
Firth-Vickers Stainless Steels Ltd. 5A
Fowler, John, & Co. (Leeds) Ltd. 106

G

Gibbons (Dudley) Ltd. 6A
Greengate & Irwell Rubber Co. Ltd. 25A

H

Halden, J., & Co. Ltd. 27A
Harper, John & Co. Ltd. 7A
High Duty Alloys Ltd. 17A
Hill & Alzen (Sales) Ltd. 8A

I

Ioco Ltd. 16A

J

Johnson, Matthey & Co. Ltd. 102

K

Kirkstall Forge Engineering Ltd. 23A
Kleen-e-ze Brush Co. Ltd., The 20A

L

LaBurn Ltd. 20A

M

Manhattan Products (B'ham) Ltd. 6A
Maxam Power Ltd. ... ... Cov. 3
McGeoch, William, & Co. Ltd. 116
Metal Sections Ltd. 13A
Mond Nickel Co. Ltd. 63
Morgan Crucible Co. Ltd., The 10A
Mulberry Co., The 16A
Mycalex & T.I.M. Ltd. 26A

N

Newton, Chambers & Co. Ltd. 108

P

Peace, Harold E., & Co. Ltd. 116

R

Roe, A. V., & Co. Ltd. 3A

S

Salter, George, & Co. Ltd. 4A
Shell Chemical Co. Ltd. 64
Shelley, L., Ltd. 24A
Sintered Metal Components (Chard) Ltd. 14A
Sintered Products Ltd. 27A
Super Oil Seals & Gaskets Ltd. ... ... Cov. 4

T

Teddington Aircraft Controls Ltd 14A
Turner Bros. Asbestos Co. Ltd. 20A

W

Weston, Chas., & Co. Ltd. ... ... Cov. 2
Whiffen & Sons Ltd. 12A
Wilmot Breeden Ltd. 21A
Whitehouse, Wm., & Co. Ltd. 24A
Wolverhampton Die Casting Co. Ltd., The 110

Published monthly by the proprietors, HEYWOOD & COMPANY LTD., Drury House, Russell Street, Drury Lane, London, W.C.2. Subscription (U.K. and Overseas) 35s. per annum, post free (U.S.A. and Canada, $5.25). Single copies 2s. 6d., by post 3s. 0d. Registered at the G.P.O. for transmission to Canada by magazine post. Printed in England by THE SIDNEY PRESS LTD., London and Bedford, November 1958.

★ CLASSIFIED ADVERTISEMENTS

3 lines 7s. 6d. (minimum), additional word 6d.—Box number 2s. extra.

For Box Numbers reply to ENGINEERING MATERIALS & DESIGN, Drury House, Russell Street, Drury Lane, London, W.C.2.

CAPACITY AVAILABLE

METAL SPINNINGS to requirements. A.I.D. approved. Martin-Golod Ltd., Maybury Gardens, N.W.10. WILlesden 3888.

TANKS, Ovens, Control Desks, Cubicles, Machine Bases, etc. ¼ Plate a Speciality. General Sheet Metal Work. Heavy Bending and Welding. —Wilston Engineering Co. Ltd., 37a, Whitton Road, Hounslow.

CAPACITY AVAILABLE. Vertical Boring; Turret, Centre and Capstan Lathes; Milling, vertical and horizontal shaping and drilling. Fabrications and components made to any specification and design. Tempest & Dibb Limited, Paternoster Lane, Gt. Horton, Bradford, Yorkshire.

PUBLIC APPOINTMENTS

LECTURER AND DEMONSTRATORS required in METALLURGY or the MATERIALS SCIENCES, to teach at postgraduate level in specialised fields. There is a particular requirement for specialists in non-metallic materials or in metal technology, but other branches are relevant. Good facilities exist for research and publication is encouraged. Demonstrators must be academically qualified and will, if suitable, be considered for subsequent promotion to Lecturer. A housing scheme is in operation at the College. Salary within scales: Lecturer £900 x £50—£1,350 x £75 —£1,650; Demonstrator: £650 x £25—£1,000; with F.S.S.U. and family allowances. Applications including names of three referees to: Recorder, Tre College of Aeronautics, Cranfield, Bletchley, Bucks. Further particulars available.

PUBLICATIONS

WIRE . . . International Register of Wire, Rod and Strip, new edition, multi-lingual, now ready, 25s. 28, Chapel Ash, Wolverhampton.

TRADE WORK

WOOD ROLLERS, RUBBER ROLLERS all sizes to 9 feet. Small turnery, Spindles and metalwork if required, send blueprint or sample. Mustills Roller Works, Ellerslie Road, Liverpool. 'Phone Stanley 2405.

HANDLEY PAGE LIMITED
seek
TECHNICAL ASSISTANTS
and
LABORATORY ASSISTANTS

A number of interesting posts occur in connection with Test Work on Aircraft Structures, Systems, Electronics, Instrumentation and Ground Test Rigs at our Radlett Aerodrome, Hertfordshire.
Both male and female staff required.

QUALIFICATIONS

G.C.E. in science subjects—O.N.C.—H.N.C. or B.Sc. in Mech. or Physics. Preference will be given to applicants with some experience in this sphere of work.

Write giving full details of experience and age to:
Staff Officer, HANDLEY PAGE LIMITED, Cricklewood, London, N.W.2.

HANDLEY PAGE LTD.
is actively engaged in the Design and Development of Subsonic Aircraft and research into Supersonic Civil Aircraft and wishes to augment its Technical Staff in the following categories:—

(a) AERODYNAMICISTS
Minimum of 5 years experience
(b) STRESSMEN
With 3-5 years Aircraft Stress experience

The Company has a long programme of work ahead, and the positions offered will give wide scope for future advancement. Salaries will be commensurate with experience and qualifications and the level of duties undertaken.
Applications in writing giving full details of experience and qualifications should be addressed to:—**Staff Officer,**
HANDLEY PAGE LTD., CRICKLEWOOD, LONDON, N.W.2.

Looking for the Right Person to do a job?

or Wanting Better Prospects Yourself?

Send your Classified Advertisement to

The Advertisement Manager, "Engineering Materials & Design",

Drury House, Russell Street, London, W.C.2. *Telephone: Temple Bar* 3422 (22 *lines*)

Minimum of 3 lines or under: 7/6. Each additional word: 6d.
Box number 2/- extra.

(Box Number added free for "Situations Wanted")

Classified display: £2 2s. 0d. per single column inch.

Advertisements must be received before 8th of the month for insertion in the following issue.

Overseas Readers!

You can subscribe to "Engineering Materials and Design" either by ordering direct from the publishers, Heywood & Co. Ltd., Drury House, Russell Street, London, W.C.2, England, or from any of our overseas agents listed in your country below. Overseas subscription rate: 35s. or $5.25 U.S.A. and Canada for one year (12 post-free issues).

ARGENTINE
Through Gordon & Gotch Ltd.
Librerias Mackern, Avenue de Leandro N. Alem, 457, Buenos Aires.
Mitchells Bookstore, 570, Cangallo, Buenos Aires.

AUSTRALIA
Alberts Bookshop Pty Ltd., 14-22, Forrest Place, Perth.
Angus & Robertson, Ltd., 89-95, Castlereagh Street, Sydney, N.S.W.
Centre of Fashion Trade Journals, 100, Flinders Street (Near Exhibition Street), Melbourne, C.1.
Engineering Publications (Aust.), 52, Pitt St., Sydney, N.S.W.
H. A. Goddard (Pty) Limited, 255A, George Street, Sydney, N.S.W.
The Grahame Book Company, 39-49, Martin Place, Sydney, N.S.W.
John Hinton & Co., 50, Miller St., North Sydney, N.S.W.
Jervis Manton (Pty) Limited, 190, Bourke Street, Melbourne, C.1.
J. W. Martin (Pty) Limited, Box H561, G.P.O., Perth.
Messrs. Swain & Co. (Pty) Ltd., Pitt Street, Sydney, New South Wales.
The Technical Book & Magazine Co., 295-299, Swanston St. (opp. Old Melbourne Hospital), Melbourne, C.1, Victoria.
H. C. Walker, Rich & Company, Grand United Buildings, 149, Castlereagh Street, Sydney, N.S.W.
Through Gordon & Gotch Ltd.
Gordon & Gotch (A'sia) Limited, 80, Currie Street, Adelaide.
Gordon & Gotch (A'sia) Ltd., G.P.O. Box 1462 T., 262/264, Adelaide Street, Brisbane, Queensland.
Gordon & Gotch (A'sia) Ltd., 511/515, Little Collins Street, Melbourne, C.1, Victoria.
Gordon & Gotch (A'sia) Ltd., 134-144, Parry Street, Perth.
Gordon & Gotch (A'sia) Ltd., G.P.O. Box 1627 B.B., Barrack & Clarence Streets, Sydney, N.S.W.

AUSTRIA
Through Continental Publishers & Distributors Ltd.
Messrs. Morawa & Company, Wollzeile 11, Vienna, 1.

BAHAMAS
Through Gordon & Gotch Ltd.
Moseley's Limited, P.O. Box 434, Nassau.

BELGIUM
Dolmen Freres, 237, Rue Royale Sainte Marie, Brussels 111 (Schaerbeek).

BRAZIL
Livraria Stark, Limitada Caixa Postal 2786, Sao Paulo.
Through Gordon & Gotch Ltd.
Casa Crashley, Ltda., 58, Ouvidor, Caixa Postal 906, Rio de Janeiro.
Publicidade Exletica, S.A., Box 539, Sao Paulo.

BRITISH GUIANA
Mr. Oswald Bentham, General Supplies Agency, Commission Merchants, P.O. Box 375, Georgetown.

BRITISH WEST INDIES
Messrs. Smith & Alfred, 4, Bellamythe Street, Woodbrook, Port-of-Spain, Trinidad.
Through Gordon & Gotch Ltd.
Stephens & Todd, Ltd., 8, Frederick Street, Port-of-Spain, Trinidad.

BURMA
Continental & Overseas Indentors, Post Box 1163, Rangoon.

CANADA
Mr. G. Bray, The Bray Circulation & Advertising, Post Office Box No. 788, Station B., Montreal, P.Q.
The Davis Circulation Agency, Oakville, Ontario.
Wm. Dawson, Subscription Service Limited, 587, Mount Pleasant Road, Toronto, 12, Ontario.
"Periodica," 5090 Ave. Papineau, Montreal 34.

CEYLON
Mr. M. C. C. Wickramanayake, Director, The City Stores Limited, 48, Ward Street, Kandy.
Through Gordon & Gotch Ltd.
W. E. Bastian & Company, 23, Canal Row, P.O. Box 10, Colombo.
Colombo Apothecaries' Co. Ltd., P.O. Box 31, Price Street, Fort, Colombo.
Plate, Limited, P.O. Box 127, Colombo.

CHILE
Marjan Sucheston K., asilla No. 9950, Santiago.

COLOMBIA
Libreria "El Gato Negro," Carrera 7A, 14-35, Oficinas 201 Y 206, Bogota.

CYPRUS
The Union Trading Co., 41, 41a, Zinonos Kitieos Street, P.O. Box 123, Larnaca.
Through Gordon & Gotch Ltd.
S. Ch. Papadopoulos, 88, Ledra St. Nicosia.

CZECHOSLOVAKIA
Artia Limited, Ve Smeckach, 30, Praha, 11.

DENMARK
Aksel J. Nielsen, Osterbrogade, 84, Copenhagen O.
Store Nordiske Videnska Bokhandel, Ronersgade 27, Copenhagen.
Johs Poulsen, The Illustrated News Service, Dahlerupgade, 1, Copenhagen V.
C. A. Reitzels Bokhandel, Axel Sandal, Norregade 20, Copenhagen.
Victor Schroder, Esq., Hovedvagtsgade, 8, Copenhagen, K.
Th. Wessel & Vett, Limited, Norregade 7, Copenhagen.

ECUADOR
Messrs. "Bravos," Publications Agency, Guayaquil.

FINLAND
Akateeminen Kirkjakauppa, 2, Keskuskatu, Helsinki.
Rautatiekirjakauppa O/Y, Helsinki.

FRANCE
Arthur Reins, 4, Square Moncey, Paris 9e.

GERMANY
American Business Journals, Zaehringerstrasse 28, Berlin-Wilmersdorf.
W. E. Saarbach G.m.b.H., Gertrudenstrasse 30, Koln, 1.
Wm. Dawson & Sons, G.m.b.H., Klosterstrasse 34-36a, Dusseldorf.

GREECE
G. Hagiantoniou, 31, Rue du Stade, Athens, Greece.

HOLLAND
G. De Vries, Lindenlaan, 10, Zaandijk.

HONG KONG
M. H. Shamdasani & Company, 90B, Nathan Road, Kowloon, Hong Kong.
Through Gordon & Gotch Ltd.
The Harris Book Company, 10, Ice House Street, Kowloon, Hong Kong.

ICELAND
Hilmar Foss, P.O. Box 154, Reykjavik.

INDIA
C. G. Beard, 49, Galstaun Mansions, Park Street, Calcutta.
Khurana Advertising and Publicity Service, 6, The Mall, Agra.
Mahajan Brothers, Opp. Khadia Police Gate, Ahmedabad.
"Manufacturers" Eastern Agency, P.O. Box 301, Bombay.
B. Muni Ratnam, Muny's Subscription Agency, P.B. No. 1653, Madras, 1.
The New Order Book Company, Ellis Bridge, Ahmedabad.
L. V. Paramesh, 12, Mandavali Lane, Mylapore, Madras, 4.
The Popular Book Depot, Grant Road, Bombay, 7.
Mr. B. L. Shah, Magazines Department, Messrs. Charles Lambert & Co., P.O. Box 4087, Bombay, 7.
D. B. Taraporevala Sons & Co., Ltd., "Treasure House of Book," 210, Hornby Road, Fort, Bombay.
The Technical Book Depot, Forjet Terrace, Tordeo, Bombay, 26.
Through Gordon & Gotch Ltd.
Central News Agency, 19/20, Connaught Circus, New Delhi.
New Photoplay Company, 231, Hornby Road, P.O. Box 61, Bombay.
Oxford Book & Stationery Co., Park Street, Calcutta.

IRAN
Palandjian Bros., Limited, Saral Omid, Teheran.
Through Gordon & Gotch Ltd.
Alfi's Stationery Shop, Avanue Zand, Abadan.

IRAQ
The Empire Trading Company, Khediry Road, Ashar, Basrah.
The Iraq Bookshop, 436A/1 Rashid Street, South Gate, Baghdad.
Through Gordon & Gotch Ltd.
Abdullah Farjo's Bookshop Ashar, Basrah.

ISRAEL
The Central Subscription Agency, 3, Ben-Yehuda Street, Jerusalem.
Mr. H. Weisz, Weisz' Subscriptions, 22, Allenby Road, Tel Aviv, Israel.

ITALY
Bruno Bollini, Via Verdi, Empoli.
Ulrico Hoepli, Corso Matteotti, 12, Milano.
Interscientia, Corso Garibaldi 34, Venaria Piemonte.
Editoriale "Maggiora," Piazza 18, Dicembre, 1, Torino 116.
C. Ruggeri & Company, Via Verziere, 2, Milan.
Sperling & Kupfer, Piazza S. Banila, Galleria Metteotti, Milano.
Guido Spiriti, Piazza Risorgimento 10, Milan.

JAPAN
F. Fujita, 586, Kita Senzoku, Otaku, Tokyo.
Fukumatsu Funahashi & Co., No. 11, 4-Chome, Kawaramachi, Higashiku, Osaka.
Marusho & Co. Ltd., c/o Messrs. Toyolite & Co. Ltd., 5, 5-chome, Kitanagasa-dori, Ikutaku, Kobe.
Kaigai Shuppan Boeki K.K., 21, Kanda Tsukasacho 2-Chome, Chiyoda-Ku, Tokyo.
Maruzen Co. Limited, 6, Tori-Nichome Nohonbashi, Tokyo.

JORDAN
Guiseppe Gedeone, Star Street, Bethlehem.

KENYA
Anglo-Tanganyikan News Agency Ltd., P.O. Box 6784, Nairobi.
Jadavji Valji & Sons, P.O. Box 506, Nairobi.
Through Gordon & Gotch Ltd.
East African Standard, Ltd., P.O. Box 380, Nairobi.
S. J. Moore, Ltd., Government Road, Nairobi.
Nzoia Press Ltd., P.O. Box 34, Kitale Superior Printing Works, P.O. Box 181, Salin Road, Mombasa.
Warners Bookshop, P.O. Box 36, Nakuru.

LEBANON
Dimitri K. Haddad, P.O. Box 786, Beyrouth.
Ets. Andraos Haddad & Freres, P.O. Box 265, Beyrouth.
Ourophian Freres Immeuble-Stephan Rue Fakhreddine, Beyrouth.
J. M. Saad, P.O. Box 352, Beirut.

MALAYA
Davies & Company, Room 22, Bank of China Building, Singapore, 1.
Fongs Trading Company, P.O. Box 220, Singapore.
M. H. Shamdasani & Co., 43, The Arcade, Singapore.
Through Gordon & Gotch Ltd.
Asia Books Company, 91, Brewster Road, Ipoh, Perak.
S. A. Azeez Bros., Railway Station Bookstall, Klang.
The Jubilee Store, 1 & 1a, Gladstone Road, Penang.
R. Kandasamy, Railway Station Bookstall, Port Swettenham, Selangar.
Kedah Bookstore, 79, Julan Langgar Alor Star.
Lim Chye Hock, 45, Station Road, P.O. Box 27, Taiping, Perak.
E. K. Yeap & Co., 20, Brewster Road, Ipoh.

MALTA, G.C.
Cachia & Company, 4, St. Anthony Street, Valletta.
Through Continental Publishers & Distributors Ltd.
Sapienza's Library, 26, Kingsway, Valletta.

MAURITIUS
Ebrahim Dawood, Dawood Building, 1, Louis Pasteur Street, P.O. Box 27, Port Louis.
The Mercantile Service Bureau, P.O. Box 262, Port Louis.
The Eastern Trading Company, Quay Square, Port Louis.

MEXICO
Sr. Emilio Minon, Apartado 2209, Ave. Arquimedes No. 91, Mexico D.F.

MOROCCO
International Press Agency, P.O. Box 182, Tangier.

NEW ZEALAND
N. Hamilton-Baker, G.P.O. 721, Wellington.
Messrs. R. Hill & Son, Plaza Building, 236, Queen St., Auckland, C.1.
Technical Books Limited, 48, Grays Avenue, Auckland.
Gordon & Gosch (N.Z.) Ltd., Linchfield Street, Christchurch.
Gordon & Gotch (N.Z.) Ltd., Jamieson Buildings, Dunedin.

NORWAY
Contact Publishing Co. A.S., Akersgt 59, Oslo.
Narvesens Litteratur Tjeneste, P.O. Box 1115, Oslo.
Norsk Bokimport A.S., Egv. Stormgt 1, Oslo.
Trygave Juul Moller (Bokhandel), Fr. Nansens Plass 8, Oslo.

NYASALAND
Blantyre Printing & Publishing Co., P.O. Box 6, Blantyre.

PAKISTAN
Ideal Subscription Agency, 42, The Mall, Lahore.
N. A. Mukhtar & Company, Sukkur, Sind.
Seafar Agencies, Grindlays Bank, Bunder Road, Karachi.

PORTUGAL
Valentim Lourenco, Rua de o Seculo 34-3, o, Lisbon.
A. Vincente Ribeiro, Avenida da Liberdade 236-1°-E, Lisbon.
Through Continental Publishers & Distributors Ltd.
Livraria Bertrand, 73, Rua Garratt 75, Apartado N. 78, Lisbon.

SOUTH AFRICA
British Technical Journals, 15, Baines House, Broad Street, Durban.
Lindex (South Africa) Pty Ltd., P.O. Box 4536, Johannesburg.
George Winderley & Company, P.O. Box 1805, Cape Town.
Central News Agency, Limited, 58, Maidland Street, Bloemfontein, Orange Free State.
Central News Agency, Ltd., P.O. Box 599, 60/62, Oxford Street, East London, Cape Province.
Central News Agency, Ltd., P.O. Box 356, 16, Adderley Street, Port Elizabeth, Cape Province.
Central News Agency, Ltd., 86, Visagie Street, Pretoria, Transvaal.

SOUTHERN RHODESIA
Messrs. Felix Sutherland (Rhodesia) Limited, 20, Orr Street, Salisbury.
Mr. V. W. Van Rijnberk, P.O. Box 238, Bulawayo.
Kingstons, Limited, P.O. Box 256, Cnr. Fife Street & Sixth Avenue, Bulawayo.
Kingstons, Limited, 89, Victoria Street, Salisbury.

SPAIN
E. Bendir, Calle Bruch 19 pral, 1a, Barcelona.

SUDAN
Through Gordon & Gotch Ltd.
The Sudan Bookshop, P.O. Box 156, Khartoum.

SWEDEN
J. Ekelund, Knislinge.
Stig Falk, Vallingatan, 13, Stockholm, 1.
A.B. Nordiska Kompaniet, Hamngatan, 18-20, Stockholm, 7.
A. B. Sjowalls Bokhandel, Drottninggatan 86, Stockholm.
Wennergren-Williams, A. B. P.O. Box 657, Stockholm, 1.

SWITZERLAND
Mr. Willi Hardi, Grossisteh No. 100 571, Ober-Muhen.
W. Frey-Schneeberger, Mattenweg 13, Lenzburg.

SYRIA
Vahan Darakjian, 291, Atfalyeh St., Aleppo, Syria.

TANGANYIKA
Through Gordon & Gotch Ltd.
Arushu Bookshop, P.O. Box 246, Arusha.

THAILAND
Through Gordon & Gotch Ltd.
Teck Heng & Co., 1326 New Road, Bangkok.
The Sales Agency Co., 1091/1093, New Road, Bangkok.

TUNISIA
Maison Allal, Allal Emma, 18 .rue Durand-Claye, Tunis.

TURKEY
Bedros Kapman, P.O. Box 2158, Istanbul.

URUGUAY
Kurt Palnitzky, Casilla Correo 293, Montevideo.
R. Raphael, Convencion 1488, Montevideo.

U.S.A.
The Overseas Publishers' Representatives, 29, West 34th Street, New York, N.Y., U.S.A.

YUGOSLAVIA
Through Continental Publishers & Distributors Ltd.
Trgovinsko Preduzece Jugoslovenska Knjiga, Terazije 27, Belgrade.